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The Mystery of Earth's Mantle

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ПОД ПОКРОВОМ МАНТИИ

ИЗДАТЕЛЬСТВО ЦК ВЛКСМ
„МОЛОДАЯ ГВАРДИЯ“

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A. Malakhov

THE MYSTERY OF THE EARTH'S MANTLE

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What is the inside of the Earth like; what mysteries does its mantle conceal? What will the sensitive feelers of superdeep holes encounter there—boiling liquid magma or superhard matter, unimaginably high temperatures or cold approaching absolute zero?

Science cannot as yet give the exact answers to these questions, though myriads of different hypotheses have been put forth.

This book tells how scientists are ferreting out the secrets of the deeper zones of the Earth; its subject is the romance of the searches and tenacious investigations carried out by geologists who have devoted themselves to the study of the depths of our planet.

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In Search of the Unknown

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An Argument

"I tell you there is positively no magma under the Earth's crust!" This peremptory declaration came from a youthful British scientist in the Moscow Metropole Restaurant at a friendly meeting of scientists just before the opening of the XVII International Geological Congress in 1937.

The young research workers were roused and began to argue, each persisting in his own opinion.

"What do you mean, there's no magma?"

"And what about Etna, Vesuvius, Klyuchevskaya Mountain?"

"And the lava fields of Kilimanjaro?"

But the Englishman was not to be daunted:

"Don't confuse surface volcanism with abyssal processes. You are all just blindly following Kant if you believe there is a fiery liquid ocean beneath the Earth's crust. There can be no liquid there. The mantle is solid! We must look for other regularities!..."

"Let's go and ask the chiefs," somebody said. "Let them settle our argument!"

We went over to the central part of the hall, where the Congress leaders sat at a number of tables pushed together. Having a quiet chat here were the two chairmen, outgoing and incoming. The former, chairman of the previous Congress, was Mr. Philip Smith, a well-known American geologist. The future chairman was Academician I. M. Gubkin, the prominent petroleum geologist. On the following day Mr. Smith would open the Congress and pass the chairmanship over to Mr. Gubkin. The two leaders were apparently discussing the details of to-morrow's procedure. And here we broke in.

Twelve young geologists surrounded the scientists and proposed a toast to the success of the Congress, to fruitful discussions, to magma, to metals.

And then one of us blurted out:

"To more oil in the plutonic depths!"

These words seemed to hit Gubkin in a sore spot.

"There's no oil in the plutonic depths! Next you'll be telling us to look for oil in the Earth's mantle?" he retorted heatedly. "The organic origin of petroleum cannot be doubted; all other hypotheses are nothing but fantasy. The idea of the inorganic origin of oil cannot even be called a hypothesis. It is a false trend in science!..."

Now the "venerables" started arguing.

According to one group of scientists the truth was enrobed in a fiery-liquid toga. Others saw it in the cold silence of the planet. Still others perceived it as gigantic rapids of hot underground water and superheated steam....

We approached the world's most prominent geologists and demanded an answer to our questions on the structure of the plutonic depths of the Earth, the Earth's crust, its mantle, and its core....

More than one scientific treatise could be compiled from the different and contradictory replies we heard. But the most curious thing was that no two opinions coincided. Moreover, the thirty scientists we questioned gave about fifty hypotheses! Still, one of them seemed to us especially daring and unusual at that time.

"All ideas of the fiery-liquid or molten state of the planet," said Academician V. I. Vernadsky, "can be traced to divine conceptions of the universe, which have essentially nothing to do with science.... It is conceivable and admissible that towards the centre of the planet the temperature falls off abruptly...."

We were embarrassed. If the luminaries of world geological science could not find a common language, then what were we, beginners in science, to do!

Soon we were utterly engrossed in the work of the Congress. It showed once again that there were no uniform views among geologists concerning a number of the most important problems of the structure and origin of the Earth and its separate parts. But this fact did not depress anyone. On the contrary, it made us all the more eager to get down to our work, and to our investigations.

A quarter of a century passed. I should have liked to meet the young participants of the Congress again, by correspondence if no other way

was possible. But I had not written down their addresses. Of course, it is not the addresses of people that are needed for a book, in the long run, but their ideas. The most important thing was that geology had made enormous progress in twenty-five years. And this was due in no small measure to the contributions of those young scientists and practical geologists. But what was the outcome of the argument? And has it been settled at all?

In the Fiery Font

"Finally we reached the edge of the crater. An intense wave of heat struck us full in the face, and at the same moment we were paralized by the sight of a huge cauldron of boiling molten gold. Fountains shot upwards one after another and fall back with a spray of fiery froth. Now and then a volley of bombs rose skywards. Bubbles burst here and there on the surface of the heavy liquid, letting off puffs of violet fumes. The violent activity was confined to three or four points of the vast lake of liquid rock. The rest of its surface just kept heaving to and fro, stirred up by the zones of intensive boiling. Hypnotized, we stared at the bright yellow line of the surf of the molten matter beating against the opposite wall of the crater."

This is how the well-known Belgian investigator and volcanologist Professor Haroun Tazieff describes one of his numerous encounters with fiery-liquid matter. He gave the world the unique cinema film "Meetings with the Devil",

pictures of real encounters with the raging, furious force reaching forth from the nether world.

Was Haroun Tazieff not among the enthusiasts who argued a quarter of a century ago about the laws governing the behaviour of molten magma under the Earth? Perhaps I could find some of my old friends here, among the volcanologists. But Haroun Tazieff was not in the list of delegates to the XVII International Geological Congress. Too bad! If he had been there he would surely have sided with the magmatists.

Yes, almost all of us were magmatists then; it was the simplicity of the theory, which seemed to account for everything, that attracted us. Guided by Kant and Laplace's hypotheses of the origin of the Earth most magmatists believed that there had been a time when the Earth was all molten, and that its surface solidified to form our Earth's crust. Beneath it lies magma, a strange substance nobody has ever seen. Its temperature exceeds two thousand degrees and it is compressed by an immense pressure of thousands of atmospheres. As a result, magma is many times harder than steel. It reacts to sharp jolts like a solid, but under slow influences spreads like a liquid. According to the magmatists, this substance is the laboratory where all rocks have been and are being formed.

Endless arguments are carried on about magma. Even magmatists argue among themselves. Echoes are still to be heard of their argument about whether the substance of the Earth's mantle is the same everywhere or different at different points. The old conception according to which it was in the molten state everywhere has

now been abandoned by geologists and geophysicists. They assert almost unanimously that there are only individual centres of molten magma under the Earth's crust, which feed volcanoes. Some scientists hold that there may be such centres in the crust as well.

In studying the activity of Klyuchevskaya Mountain, the largest volcano in Eurasia, Professor G. S. Gorshkov of the Kamchatka Volcanological Centre established that during eruptions the contours of an immense underground hearth 30 or 40 kilometres in diameter and up to 10 or 12 kilometres thick can be traced. This hearth occurs as a huge lens below the Earth's crust, 50 or 60 kilometres below the surface.

American geologists hold that volcanic hearths may occur at depths of as much as 100 or 150 kilometres. That is, these hearths are located in the uppermost zone of the Earth's mantle, just below the Earth's crust. Not so long ago the Japanese geophysicist Yokoyama made a magnetic survey of the Island of Oshima and found the magnetic field to be normal all over the island. But when he had finished the Mihara volcano unexpectedly came to life, and Yokoyama repeated his magnetic survey. This time he discovered that a magnetic anomaly had appeared under the island! Yokoyama calculated the depth of its occurrence, assuming it to be due to the volcanic hearth. And he found that the top of the anomaly was only two kilometres below the Earth's surface! He thus came to the conclusion that volcanic hearths are seated not in the mantle, not below the Earth's crust, but right in the crust itself.

Arguments about volcanoes and volcanic activity have been going on since ancient times. Many naive views were put forward in India and Greece. Some held that the fiery-liquid substance was belched forth by dragons, and others called it the breath of the awful Chimera who breathed clouds of fire and smoke on all who approached its cave. Greek mythology also tells the story of Typhon, one of the Titans, who fell to Earth during a fight with Zeus. His body gave off such intense heat that all the Earth around melted. Many myths and legends are connected with Vulcan, the underground god after whom the fire-belching mountains were named. But just now we are talking of neither the Chimera nor the Titan Typhon, but of magmatic hearths.

Of course, it cannot be said that all the volcanists' ideas are disputable. Their creed includes unquestionable truths. The fiery font gives birth to rocks, and from the type of volcanic activity we can forecast the kind of rock that will result in each particular case.

There is a volcano in the centre of the Pacific Ocean, on the Hawaiian Islands, called Kilauea, which has more than once shown signs of life. The last eruption was in 1960 when the inhabitants of the Hawaiian Islands again saw fiery fountains appear above its crater. The fountains flew upwards faster and faster, higher and higher. The crater then began to overflow and the lava rushed down at a mad rate. It swept away all obstacles in its path. The villages were protected by dykes which served their purpose well enough during minor eruptions. But that day they proved unequal to the task and broke down. The villagers

had no time to call a squadron of aircraft to bomb a new road for the fiery torrent, and the lava rushed down on to the sugar cane plantations and vineyards, destroying everything in its way. It reached the seashore where there was a settlement; a moment later this was all aflame. A headlong stream of lava poured into the sea. In an instant everything was in turnoil, a dense cloud of steam rose up, and it became as dark as night. For a long time the terrible picture of the catastrophe was hidden from the survivors....

Scientists know that a specific kind of rocks called basic or basaltic results from such liquid lava when it contains almost no gases. Such rocks contain a relatively small percentage of silicic acid. They are abundant on the volcanic islands of the Pacific Ocean. Wherever basalts are formed the lava discharge occurs in the same way as from the Kilauea volcano in 1960.

Geologists picture the formation not only of the Hawaiian relief in this way. Some scientists believe that the volcanoes on the Moon had a similar origin and that the lunar craters are formed in precisely this way. Recently the Soviet astronomer N. A. Kozyrev was fortunate enough to observe a discharge of gases from the Alphonsus Crater, accompanied by eruption of the volcano. But these gases were of a strange composition. They contained a great deal of carbon and hydrogen. Such gases are not often found in volcanoes on the Earth. Perhaps this discharge of gas was related to processes other than volcanic? Not all scientists admit the existence of volcanoes on the Moon. Many believe, for instance, that the craters are the result of bombardment of the

lunar surface by large meteorites. There is no atmosphere there, and the celestial invadors would be capable of tremendous devastation.

Everybody has heard of the terrible catastrophe of 79 A. D. that destroyed three cities—Pompeii, Herculaneum and Stabiae at one stroke. An eye-witness of this catastrophe, the writer Pliny the Younger, wrote in one of his messages to the historian Tacitus that suddenly an immense mushroom-shaped cloud appeared above Vesuvius. There was a great explosion. The cloud grew larger every moment and gradually covered the whole sky. It became as dark as night. Burning ashes began to fall and red-hot volcanic bombs flew out of the crater. The ashes mixed with the rain water falling from the cloud and torrents of mud began to flood the city. Those who escaped the volcanic bombs were caught up by the furious storm, and whoever was able to save himself from the bombs and the mud was liable to be suffocated: the air was saturated with poisonous sulphurous fumes. Thus perished Pliny the Elder, a famous naturalist of that time.

And in 1944 there was another major eruption of Vesuvius. Very viscous lava, quite different from the lava on the Hawaiian Islands flowed out of the crater. Its front part was almost vertical and about as high as a four- or five-storeyed house. American flyers succeeded in filming this unusual sight. Afterwards we saw on the screen how the flow moved. Its progress was slow; a man on foot could easily escape from it by running. But everything in the path of the lava was demolished.

Scientists studied the composition of the rocks of the Vesuvian flow and found that the lava differed from that discharged from the Kilauea crater. Here there was more silicic acid, which is the basis of classification of all magmatic rocks. Vesuvian lava is called intermediate. Rocks that contain still more silicic acid are known as acidic. These acid rocks, for example, liparite, are also found in zones of volcanic activity, but the eruption of volcanoes which give such lava is of an entirely different nature.

The volcano Bezymyannaya has long been known in Kamchatka. It was thought to be quite extinct; for many decades it had shown no signs of life. But on March 30, 1956 a great catastrophe occurred. Suddenly, as Professor G. S. Gorshkov related, ashes and bombs began to fly up from the crater, reaching a height of 40 kilometres. The explosion was terrific. All the trees, bushes and plants within a radius of 25 or 30 kilometres around the volcano were destroyed. Everything in the vicinity was ruined, mangled and burned. When investigators were able to approach the crater they found there solidified lava as well. It was rich in silicic acid.

Wherever the investigator goes—to the Pacific coast, the central part of the Mediterranean, Central Africa or Central America—wherever there are volcanoes, he can always tell by the type of activity whether basic, intermediate or acidic rocks form there.

Assuming that in remote geological times, millions of years before our own, geological processes took place in the same way as they do now, geologists come to the conclusion that wherever

acid igneous rocks are found there existed volcanoes of the Bezymyannaya type. Where intermediate rocks occur, volcanoes similar to Vesuvius were once active. Areas in which basalts are encountered are the regions where there were eruptions similar to those of Kilauea. Scientists consider that volcanoes of all three types existed on the eastern slopes of the Urals 300-400 million years ago, because basic, intermediate and acid rocks are all found here. There were also such volcanoes on large areas of the territory of Siberia, and it is with them (particularly, with the zones of major eruptions) that the formation of diamonds is connected.

At present one of the volcanoes in the Asiatic part of the Pacific Ocean is surrounded by numerous hot water springs. These waters contain large amounts of various salts, including those of iron, copper and other elements. In the course of a year these subsoil waters carry away as much copper as is contained in a major copper deposit. Geologists consider many copper deposits to have been formed in this way; the copper salts from hot solutions accumulated in the rocks giving rise to the beds of copper ore that are mined now on the eastern slopes of the Urals, in Kazakhstan and other places.

But by no means all the difficulties involved in accounting for the origin of copper deposits can be overcome by means of the magma theory. For instance, the formation of copper in the deposits of the eastern slopes of the Urals is not quite clear. Though copper has been mined there for many centuries, the theory of its formation has not yet been developed.

In the nineteen twenties Academician A. N. Zavaritsky put forward the hypothesis that the copper compounds and associated minerals were incorporated into the sedimentary rocks of the Urals as a specific sulphide magma. On cooling they formed bodies of definite shape, mainly lenticular. Many scientists became adherents of this theory. But it was soon found that it did not tally with the facts. Especially contradictory to this hypothesis were the data on the Sibai Deposit where petrified organic remains were discovered in the sulphide rocks. Now, what kind of magma would that be?

A group of scientists suggested that the principal role in forming the copper deposits might have been played by the hot waters that issue in the peripheral zones of the magmatic hearths, and that the Ural deposits originated in approximately the same way as those forming at present in the region of the island volcanoes in the Asiatic part of the Pacific Ocean where copper-bearing waters are accumulating, or rather issuing. This standpoint was also put to the test of practice. For a long time it seemed the right one, and then it too was disproved by facts.

In 1936 a new hypothesis was put forward by Academician Zavaritsky. He assumed the copper to be related to ancient volcanoes. This was how the Kuromono Deposit in Japan, described by the geologist Kameki Timoshita, was formed, for instance.

But this hypothesis did not withstand the test of time either. There are many current hypotheses concerning the origin of Ural copper. These hypotheses are being verified and there are always

new facts coming up, some of them disproving and others confirming the hypotheses.

When studying mountain formations we very often come across once existent, but now cold volcanic hearths. We call the rocks constituting them intrusive, considering them to have been thrust in from the Earth's mantle ("intrudio"—"I thrust in") without reaching the surface.

A classification similar to that of volcanic rocks has been worked out for the different kinds of intrusive rocks. Among them we find basic, intermediate and acid rocks, as well as ultrabasic and ultra-acidic rocks, which contain very small and very large quantities of silicic acid, respectively. A great variety of metallic and non-metallic minerals are related to such cold magmatic hearths: iron, copper, gold, platinum and many kinds of nonmetallic minerals, such as asbestos, mica and precious stones. But when we investigate now cold magma hearths we do not consider that the intrusive rocks constituting them once occurred in the mantle under the Earth's crust. We see distinctly that they are situated in the Earth's crust itself.

It was the connection between a great variety of minerals and cold magma hearths that urged us young geologists to undertake an exhaustive study of these relationships and reveal them in all parts of the globe. And perhaps the British sceptic was right?

Twenty-five years have passed, but even now not all the laws of formation of minerals are sufficiently clear to us. For example, we relate deposits of chromium, or rather, the mineral chromite, a complex oxide of chromium, to the very

first stage of solidifying of magma. We say that in magmatic hearths the heaviest metals sink to the bottom, while the lighter ones float to the top. That is the cause of the primary redistribution of substances in the magma. Chromites and platinum are the heaviest substances, and they sink to the bottom of the hearth, collecting there either as small grains or in the form of larger or smaller accumulations. Chromite forms at high temperatures, close to one thousand five hundred degrees. All this follows logically from the magma theory.

But once when geologists were drilling a well in the Middle Urals a powerful jet of gas suddenly shot up from a depth of 600 metres, from a zone containing inclusions of platinum and chromite. The gas was found to contain a large percentage of hydrogen and methane, the latter being of organic origin, as many chemists believe. And this in the zone which was once the deepest part of a magmatic hearth, where the temperature exceeded a thousand degrees!

But maybe methane is a characteristic gas of magmatic hearths? As far back as 1933 Academician Vernadsky put forward the idea that methane may be formed both in zones of activity of live organisms and in the course of magmatic processes.

Very many regularities in the structure of volcanic apparatuses and the occurrence of geological processes are elucidated at special stations which study present-day volcanoes. Such work requires great strength, courage and fearlessness on the part of the investigator. For example, two workers at the Kamchatka volcanological centre, V. F. Popkov and I. Z. Ivanov, were given

the job of measuring the temperature of a lava flow. They could not throw the thermometer into the lava, but still the task had to be fulfilled. Then they noticed a huge lump of solidified rock floating on the surface of the red-hot lava like an iceburg on water. The volcanologists sprang on to this rock, broke a hole through it with a crowbar, and let down a special thermometer: it registered over 800 degrees. The investigators jumped off the rock, returned to their station and reported their task completed!

Or here is another case, not unusual in the work of volcanologists. Henrich Steinberg, head of the volcano-physics section, was ordered to investigate the rocks in the very crater of Avachinskaya Mountain in Kamchatka and to take samples of volcanic gases there. He climbed down into the crater. Putting his knapsack on one side, he began to collect rock samples and to take samples of gas in special cylinders. Having finished his work he noticed that the knapsack, which he had left on a rock, was burned through. Steinberg measured the temperature of the rock and found it to be above 400 degrees!... The volcanologist and his co-workers remained in the crater of the Avachinskaya Mountain for over two and a half hours. They left only when their breathing apparatuses began to let in volcanic gases.

What is it that makes volcanologists brave the scorching heat of the crater to collect data on the temperature, pressure, gas composition, etc., at the risk of their lives?

To find the answer to this question we should visit Dushinskaya Street in Moscow. There we can see something resembling a volcano. Yes, in

Moscow itself, on Dushinskaya Street we can see a molten fiery-liquid mass, only it is melted artificially at a temperature of 1,000-1,200 degrees. Volcanologists had hinted that the best material for this purpose would be the basic rock basalt. Here, at the stone foundry, the workers learned to pour the molten basalt into moulds and make pipes, plates and many other things from it. Basalt wares are acid- and heat-resistant; at special plants they substitute metals. And, of course, all this is a practical result of the research carried out by volcanologists.

Another practical result is the use of volcanic heat or "red coal" as power engineers call it, for industrial purposes. Several power stations in Italy, New Zealand and other parts of the globe operate on hot steam heated near volcanic hearths. Volcanic heat will be harnessed in the U.S.S.R. too; a pilot station is under construction in Kamchatka, and the construction of several more is to be started shortly.

But the properties of fiery-liquid melts interest volcanologists mainly from the point of view of the economic minerals contained in them and formed from them. If the substance of the mysterious mantle of the Earth is really the original source of all economic minerals, there can be only one conclusion: we must investigate further and reach down to this source, and so free ourselves from blind obeisance to silent nature. Perhaps volcanoes are channels through which the substance of the mantle breaks out on to the surface, though in altered form.

By studying volcanoes we get a great deal of unquestionable data concerning the formation of

igneous rocks and the mechanism of volcanoes.

But how many unsolved problems remain! How much work has still to be done before we know the depth of the hearths feeding the volcanoes, the composition of the substance of the Earth's mantle, and the relation between hydrocarbons and magma! And how does the magma originate? To answer these questions we must first turn to the history of the great faults of our planet, because these are the places where magma could come out on to the surface and leave its tracks.

The End of Gondwana Land

Volcanologists say that a change in pressure is all that is needed to start lava flowing out through faults from the mantle zone, under the Earth's crust, on to the surface. They assert that the substance of the mantle, though at a very high temperature, is solid because the enormous pressure there keeps it from turning into a liquid. Yes, it would be relevant to make a more detailed study of the faults in the Earth's crust.

I was once invited to join a group of tourists who were going to tour Africa. I accepted gladly, for on the way I would see the fault zones. The first of them would be that of the Bosporus and the Dardanelles.

Further on we would come to the remains of the mysterious Gondwana Land. Gonds is the name of a tribe, and Wana, of a country in India. These two words together make up the name of a vast continent which, according to scientists,

was situated where India, Australia, Africa and South America are today, including great expanses now at the bottom of the Indian and Atlantic oceans. And here I would come across traces of the faults that tens of millions of years ago caused the breakup of this gigantic continent.

I was impatient for our ship, the Felix Dzerzhinsky, to enter the Bosporus. Geologists say that a million years ago, at the beginning of the Quaternary Period there was a closed Black Sea lake like the present Caspian, rich in fauna adapted to life in a fresh-water basin. The Dniester, Dnieper, Don and Danube poured such great masses of fresh water into this basin that the lake had a very low salinity. Then there was a catastrophe during which part of the dry land sank, forming a strait, and the salt water of the Mediterranean rushed into the Black Sea. The inhabitants of the fresh-water lake were unable to adapt themselves to the sharp change in conditions, and perished. To this day the waters of the Black Sea are infected with the products of their putrefactive decay, mainly hydrogen sulphide. The infected zone can be traced, beginning at a depth of 200 metres, down to the sea floor. Life is possible only in the surface zone of the Black Sea. There is hardly any life in the depths.

At last we reached the Bosporus, its coasts lined with luxurious villas, and the innumerable minarets and domes of the mosques of ancient Istanbul. These contrast vividly with the business section of the city, built in American style.

In the Bosporus and the Dardanelles I saw clearcut terraces on the slopes of the strait. It is known that terraces could have formed only if

a river had flowed here. Terraces are geological traces of variations in the sea level, imprinted on the banks of a river emptying into the sea. I saw not a single trace of the cliffs there should have been here if a fault had occurred.

When I pointed this out to experts they brushed my doubts aside by assuming that the water that rushed in through the break had erased all such traces, leaving only the terraces.

After this came what are known as exotic places and, of course, geology was forgotten. We were passing by the coasts of Troy. A short time before, archaeologists had found a vessel somewhere around here dating back to the Trojan war. Lines from Homer's *Odyssey* and *Iliad* came to mind.

Then we stopped at Piraeus, a major Mediterranean port, which has now merged with Athens. We took a bus to the Athens National Museum and then visited the Acropolis with its famous temples and no less famous centuries-old history. Legends rose up at us from all sides. Again we had no time for geology!

Geology was forgotten when we arrived at Port Said and took a trip from there to the famous pyramids and sphinxes near Memphis. We stood beside these great monuments and sensed the milleniums of human culture. Even the hundreds of millions of years of the Earth's geological history did not seem so impressive here.

Further on began another zone of faults in the Earth's crust, which took place many millions of years ago, and I wanted to see it.

Some scientists claim that about 60 or 100 million years ago tremendous bulges formed in

the zone of the present-day Red Sea, in the upper reaches of the Nile and still further south. They took shape gradually. First various kinds of arches were formed with their centres lifted up as high as one kilometre, then followed terrible earthquakes, and the bulge zones turned into gigantic depressions. Lava poured out through the faults forming vast fields of volcanic rocks.

Two main lines of faults have been outlined in Africa; the Eritrean and the East-African. The Eritrean line coincides with the Red Sea zone. The East-African one runs from the upper reaches of the Nile to the zones of lakes Tanganyika, Albert and Kivu, where it branches out somewhat to converge again into a single line in the southern parts of the African continent. To get to it we had to pass through the Suez Canal into the Red Sea.

Perhaps I was too sceptical, or perhaps there actually is no confirmation here of what I had read in scientific papers, but somehow I was disappointed in both the Red Sea and the Gulf of Aden. I saw no definite indications of the system of faults shown in geological maps.

We had several stops and interesting encounters on the way; we admired the unusual picture of the mixing of the waters of two oceans, the Indian and the Atlantic. Their waters differ sharply in colour. But I came across neither geologists nor volcanic rocks. Where we might have seen rocks we were too far from shore, and where we might have met geologists we were told they were out prospecting.

When we had left the Cape of Good Hope astern, the people on board asked me to tell them

about the mythical Atlantis. So I told them how many, many years ago there was a legend about an ancient continent called Atlantis, somewhere in the Atlantic Ocean or maybe somewhere else. The first to write about it, almost 400 years B. C. was Plato who had it from his great-great-grandfather, the Athenian sage Solon who, in his turn, had heard it from the Egyptian priests. It seems the king of Atlantis had made up his mind to enslave the Athenians. But in a decisive battle the Atlantides were defeated, and soon after Atlantis with all its inhabitants and towns sank to the bottom of the ocean.

What a variety of hypotheses have been put forward about the whereabouts of Atlantis! It has been located in the Sargasso Sea, in Armenia, in Sweden, in the Caucasus, and in the mouth of the Nile. Not long ago, for instance, Acadomician D. V. Nalivkin suggested that the myth of Atlantis reflected some vague information about Greenland.

Recent investigations have thrown some light on the riddle of Atlantis. Professor N. F. Zhirov, who took an interest in the problem, drew attention to the coincidence of certain dates in many legends and even in calendars. The ancient Assyrians and Babylonians began their chronology from a certain event that took place eleven and a half thousand years ago. We ended up with about the same figure not long ago when studying the origin of the Gulfstream with the aid of atomic time counters. It appears that its warm waters did not reach the North as recently as 12 thousand years ago. They broke through to the North only after a certain event, and caused a sharp rise

in temperature. Glaciers began to melt away, and swamps appeared. At one time a mammoth got stuck in one of these swamps on the Taimyr Peninsula in Siberia. Its bones were investigated with atomic time counters and showed that the Taimyr mammoth had perished about 12 thousand years ago.

A group of American scientists undertook a study of the soil from the bottom of the Atlantic Ocean, and found traces of volcanic ash which had accumulated on the ocean floor also 12 thousand years ago.

A comparison of these figures led Professor Zhirov to assume that all these events were related to the disappearance of Atlantis.

Possibly the continent broke up into pieces and sank into the ocean, removing the obstacle that had prevented the waters of the Gulf of Mexico and the Caribbean Sea from coming north. The catastrophe was accompanied by a volcanic eruption, and immense outpours of lava came up to the surface through the faults. It was the traces of this volcanic ash that the Americans found at the bottom of the Atlantic Ocean.

One more curious fact. About 100 years ago a cable was being laid between London and New York. During the work the cable broke. It was retrieved and hauled to the surface by huge grapnels, bunches of anchors bound together. The fluke of one of the anchors held a piece of rock from the floor of the Atlantic, which turned out to be solidified lava. But experts say that it froze on land and not at the bottom of the ocean. This is yet another piece of evidence in favour of the existence of Atlantis!

Our voyage was coming to an end. Here was Gibraltar, and here the Great Etna, Stromboli.... We visited the ruins of Pompeii, Herculaneum and Stabiae and passing the Aegean Sea, the Bosporus and the Sea of Marmora, we approached our home coast again.

Influenced by our talks and the impressions of our tour I got the idea of writing a science-fiction novel or at least a story of the history of the Earth. I even had the outline of the plot worked out. An expedition of geologists sets out on a spaceship for the Moon. The expedition is equipped with the most sophisticated apparatus, including a time machine. The geologists are to set up this machine in one of the lunar craters, connect it with a cine camera and point its lens at the Earth. What a film it would be!

I started thinking how I would show earthmen all those far-off events, but here I came to the very question: just what would I show? Which geologist's, geophysicist's or other scientist's opinion would be the best to represent in the film?

According to Indian cosmology—the science of the origin of the universe—the Earth consisted at one time of seven continents. They spread out like lotus leaves from Mount Meru, the general centre of the universe. Afterwards the continents floated away from this centre and were separated by seven oceans. Approximately the same idea was suggested in 1877 by Y. V. Bykhanov, a Russian amateur astronomer. He noticed the astonishing coincidence of outline of the American and Euro-African coastlines. If we imagine these coastlines moved together they fit so well that

not a crack remains between them! And Bykhanov assumed that a once uniform continent had split into parts which have been moving ever since.

This idea was again put forward 33 years later by the famous geophysicist Alfred Wegener, and the floating continent hypothesis is now generally known in science by his name. Wegener assumed that the original single continent Panghea (All-Earth) was broken up into pieces. Like lotus leaves they separated from one another and floated away, divided by the oceans, giving rise to the modern continents.

I supposed that the expedition which flew to the Moon would film the moments of faulting, and the violent volcanic activity, and the separation of the continents by the oceans.

Amateur cine-photographers know what stop motion photography is. A cine camera is set up, for instance, in front of an unopened flower. One frame is exposed, say, every half-hour, and then all these exposures are projected on to the screen at the usual rate. The bud blossoms out quickly before the spectators' eyes into a beautiful flower. It was just such stop motion photography that I intended to employ in the science-fiction story from one of the lunar craters, to show how the continents drifted apart.

And now, here we are in the cinema. The lights dim slowly and go out, and pictures of the primeval chaos of the Earth pass across the screen before us one by one. The outlines of the continents seem strange and unfamiliar. The whole Earth is one continent surrounded by the World Ocean. The planet zooms towards the spectator

to show some individual close-ups of the past of our Earth, taken automatically by the camera.

A green carpet of strangely familiar plants stretches along the ocean shore. The camera brings us close to the world of dendritic ferns, horsetails, lycopods.... On a fallen moss-covered tree near a lake lies a monster with the mouth of a crocodile. Its head is coated with armour. Beside it we see the remains of a huge frog-like creature; the end of one of the episodes of the great struggle for existence. Hovering above the battleground are gigantic light-winged dragon-flies....

The shape of the crocodile-like creature's head, the vegetation and the entire appearance of this world are evidence of very ancient stages of evolution. All the paleontologists present at the show are unanimous in declaring this to be the fauna and flora of the Upper Carboniferous, one of the most distant geological epochs, dating back to three hundred or three hundred and twenty million years ago.

Another tremendous rush. Now we again see the whole Earth. Its rotation stops for a moment, and we see the continent breaking up. The lines of gigantic faults form the contours of North and South America, Africa, Antarctica, Australia.... And the continents drift apart just like the lotus leaves in the Indian tale. Before our eyes are born the oceans separating them; the Atlantic and the Indian.

This process took over three hundred million years, but with the aid of the wonderful stop motion machine we were able to see it in a few hours.

Then we were shown a different film. It was also about the history of the Earth, but this time

according to Staub, instead of Wegener. The German scientist held that the entire history of development of the Earth consists of constant shifts of the continent Gondwana, and the northern continent, Laurasia, which was situated where Eurasia and North America are today. Under the action of centrifugal forces Laurasia and Gondwana kept colliding with each other and drifting away again towards the poles. According to Wegener the continents drifted calmly away from each other along the latitudes, but according to Staub they moved along the meridians.

But Wegener and Staub were not the only authors who put forward hypotheses. I counted over five hundred hypotheses of the origin of the folded mountain ranges on the Earth and imagined the poor cameraman in the lunar crater changing those stop motion films to show us five hundred versions of the destruction of Gondwana!

According to modern ideas the beginning of the end of Gondwana is pictured differently from what Wegener or Staub thought. Evidently, vertical shifts of the continents played a major part. Various sections of Gondwana were displaced now upwards, and now downwards along the lines of faults. It is thought that part of Gondwana sank in the zone of the present Indian Ocean, and the islands in this ocean are but the peaks of high mountains in that part of Gondwana. Perhaps part of the Pacific Ocean and the region of the Atlantic Ocean between South America and Africa are also a sunken section of the once integral continent of Gondwana.

What does all this amount to? I hunted for the faults of Gondwana and some of Laurasia,

but saw none of those faults. True, I have no grounds for disbelieving my geologist and geophysicist colleagues, but the very abundance of hypotheses and contradictory opinions throws doubt on many accepted truths. That volcanic activity is confined to certain definite lines is a fact. But are all the lines indicated valid? Is everything so well thought out in the magmatists' theory? The facts they operate with may be unquestionable, but their theoretical generalizations are clearly wanting.

Rock Rhythms

Ancient Hindu legends tell of how the god Brahma ruled the world. When awake he created, but when he rested he destroyed everything he had made. And this was the origin of world fires, floods and other catastrophes. Epochs of destruction alternated periodically with epochs of creation.

Everybody knows the views of the ancient Greek philosopher Heraclitus who lived about 500 B.C. He taught that the world experiences constant changes, that epochs of destruction give way to periods of creation: "The world is and will be eternally a live fire, regularly flaring up and dying down again."

It is self-evident that these conceptions of periodic stages of destruction and creation were based on observation. The scientists of antiquity observed the geological work of the sea surf, saw mountains destroyed, and experienced major earthquakes, landslides, and avalanches. But

they were still far from a scientific understanding of the laws of the life of our Earth.

If we continued the fantastic picture in which we filmed the Earth's surface from a lunar crater, using a special time machine, investigators would see how individual parts of our planet kept sinking and rising again, the amplitude of these movements being tremendous. For example, the rising of the coast of the Gulf of Finland seems fairly modest at first glance; only about a metre per century. But if we took account of all these movements over millions of years and followed the rhythm of rise and fall in all parts of the Earth's surface with a cine camera we should get a very impressive picture. In the course of five or seven million years the Caucasus reached its present height of more than five and a half kilometres above sea level, while the Himalayas, the Pamirs and other mountain edifices rose even higher during the same period of time. And what is a mere seven million years to our planet!

In other parts the Earth's surface is sinking. Even with our time machine we could not follow the fate of these sinking sections. We should have to film our picture in rays of some kind that would make it possible to penetrate a thick layer of water. Then our shots would show that many sections of the Earth's surface have turned into the deepest depressions of the globe, sinking to a depth of 10-11 kilometres below the surface of the World Ocean, and that this happened not so long ago. We should see that the surface of the ocean floors is not at rest either, not even for a minute.

The synchrotron in Geneva can operate only

during periods of complete rest. Its operation is affected even by the very slightest changes in the surface of the Earth's crust due to ebbs and flows occurring hundreds of kilometres away from the unit. And as it takes part in these movements of the Earth, the Geneva synchrotron can operate only about 30 hours a week; all the rest of the time the surface of Switzerland is vibrating.

It has been established that the entire territory of Moscow daily rises or falls about half a metre from a certain average level. These rises and falls are due to daily ebbs and flows caused by the gravitation of the Moon and the Sun.

The question of the forces that cause these movements of the Earth's crust is still greatly disputed, though we are quite familiar with their geological consequences which we register continually in the course of our geological work. Why is Holland sinking while Finland is rising? Why were the Pamirs and the Himalayas lifted to such a tremendous height? What is the basis of the processes which form mountains? Science still has to find the answer to these questions.

Geologists have suggested a large number of hypotheses to explain this problem. Some say that the movements are due to the contraction of the Earth. Others assert that they are caused by its expansion. Still others claim that the mantle plays a major role in these processes. There are those who relate them to outer space, and others again who visualize a relationship with the rotation of the Earth around its axis, etc., etc.

Y. A. Lyubimova who studied the thermal system of the Earth, states that at present our planet is contracting. According to her calcula-

tions we are now experiencing a lapse in volcanic activity, which was much stronger 300 to 400 million years ago.

But V. V. Belousov asserts that the Earth is expanding due to the heating and melting of its basaltic layer, which is also stimulating its volcanic activity. As we know, the volume of a body increases when it melts, and this results in faults in the Earth's surface.

I. V. Kirillov and V. B. Neiman also hold that our planet is expanding. In their opinion the ocean regions are the zones of expansion. Kirillov has built some curious models of the Earth. One of these models, which reflects the embryonic stage of development of our planet, has a faulting pattern resembling that of the Martian canals.

How can these directly opposite points of view be reconciled?

We come across a still greater number of problems and questions when we begin to study the history of the origin and development of mountains, and the history of the Earth as a whole. About thirty years ago the epochs of development of our planet were outlined quite distinctly. Hans Stille, the great German scientist, formulated the science of the rhythms of development of the Earth—rock rhythms. Each rhythm, according to Stille, included periods of sedimentation, folding, mountain building and destruction of protogenic mountains. Folding was a violent process; the periods of sedimentation were relatively tranquil.

During the epochs of folding and mountain building great faults appeared in the Earth. At these periods certain parts of the Earth's crust

were subject to sharp upheavals which resulted in the formation of mountain ranges.

Stille counted no less than thirty such rhythms in the history of the Earth, which have been called Stille's canon (rule). At one of the international congresses a motion was carried for geologists to adhere to Stille's canon. But afterwards these rhythms in the life of the Earth, and all the epochs outlined by Stille, were sharply criticized. It was probably largely his own fault that his views finally began to be refuted by his colleagues; he was not always able to indicate the exact age of mountain formation. In point of fact, it is very easy to make a mistake when studying mountain-making epochs. The geologist bases his observations on what is known as disconformities of rock occurrence. These disconformities are disclosed after the rocks forming the mountain range are demolished and undisturbed horizontal layers are deposited on them.

How long would it take to break down the Crimean or the Caucasian mountains? Quite a long time, of course. It would all depend on whether only the action of the sea is involved, or whether rivers also cut into the depths of the range, or glaciers are helping to wear it down.

On the Mzymta River near Sochi scientists discovered a cave containing tools which dated back to the Stone Age. At that time there was a river just in front of the entrance to the cave. But now the Mzymta has cut deep into the ground, and the cave is 110 metres above the water level in the river. At least 100,000 years separate us from the ancient Stone Age. Thus, every thousand years the river "shaved off" a layer one metre thick!

Then how many years would it take to completely demolish a mountain range five or seven kilometres high? The rate of destruction of the range will depend on the speed with which it was thrust up, on the strength of the rocks, and on many other factors. For a long time there existed several points of view as to the duration of rock rhythms, two of them being general, extreme viewpoints. One of them was called catastrophism (more precisely, neocatastrophism) and the other evolutionism (neoevolutionism).

The neocatastrophists say that folding seizes the entire globe momentarily, as it were, in a kind of paraxysm, so that it is exhibited simultaneously in many parts of the Earth's surface. In its time the doctrine of stages of destruction spreading catastrophically over the globe was condemned by science. Catastrophism in its pure form led to the idea of repeated acts of creation by some deity, of all that exists on Earth, and subsequent destruction of these creations, just as in the Indian legend or in the Bible. This closeness of the catastrophic standpoint to religious doctrine made many scientists deny the theory of momentary acts or momentary catastrophes in the history of the Earth.

Naturally, the idea arose that the phenomena taking place on the Earth are drawn out in time. This was evolutionism. Nowadays evolutionists say that the process of folding takes many millions of years. In his time Academician N. S. Shatsky contended that all the folded ranges of the Caucasus took tens of millions of years to form. He positively denied isochronous "acts of creation" of mountain ranges on the Earth.

At present we consider both these extreme viewpoints erroneous. When we examine the consequences of geological processes, including folding, we often cannot estimate how long or how short a time they took. Even today we have strong earthquakes, and volcanic eruptions take place, but afterwards, when the results of these phenomena are reflected only in rock records, investigators will argue, as they do now, whether those processes were catastrophic or evolutionary.

And even we, estimating them at present, will also say that in places they indeed take the form of sharp catastrophes, such as powerful earthquakes accompanied by intense volcanic activity. But considering the planet as a whole these are but insignificant phenomena, insignificant stages drawn out in time over perhaps 100, 200 or even 300 thousand years. What is this, catastrophism or evolutionism?

It is neither the one nor the other. It is a pulsating process of formation of faults, volcanoes, folded rocks, upheavals and sinkings of the Earth, drawn out over a fairly short period of time. This is something entirely different from the ideas of either the catastrophists or the neo-evolutionists.

Only lately, owing to the use of atomic time counters has it become possible to establish the approximate duration of rock rhythms. It appears that during the three thousand million years of the Earth's history there were no more than 20 major rhythms lasting 100-200 million years each. In their turn, the major rhythms include dozens or even hundreds of minor rhythms, each lasting

several million years, and the latter break down into still smaller rhythms.

The rock chronicles of the Earth have only just begun to reveal their secrets. That is why the study of these questions gave rise to so many different hypotheses.

Meanwhile, the controversy between scientists is far from being purely theoretical. The process of formation of many minerals, metallic and otherwise, is related to rock rhythms. These rhythms set up conditions in which particular kinds of minerals are concentrated in one zone or another. The usual crumpling of rocks leads to alternating bulges and downthrows of the Earth's layers. As a rule, accumulations of mineral oil are confined to bulges. Oil, gas and water occur here, arranged according to their specific gravities: the gas occupies the topmost part of the porous layer, then comes oil and then water.

Where mountain building processes have left depressions in the Earth's layers we find water to have accumulated owing to the same law of distribution of fluids according to specific gravity. This is what is known as artesian water. If a hole is bored in such a layer a fountain shoots up from under the ground. These artesian basins are in many towns the main, and sometimes the only sources of water supply.

Volcanism, and faulting, and all the minerals confined to the active zones of the Earth are also related to the rock rhythms. There are people who have devoted their lives to establishing the regularities of the relation between the pulse and rhythm of the Earth and various minerals, but we see now how many riddles they have still to solve.

Laws or Riddles?

There is much in geology that is indisputable. Such are the laws on which the science is based. Very many such laws have been established in mineralogy and crystallography, in the theory of the conditions of rock formation.

For example, the Russian scientist Yevgraf Stepanovich Fyodorov established by mathematical analysis that there is a limited number of ways in which minerals can fill space. He proved mathematically that only 230 crystallographic arrangements are possible.

Fyodorov lived to see the triumph of his mathematical analysis; the mathematical laws he had established were confirmed and proved by experiment, by X-raying minerals. These laws were found to be related to atomic and molecular lattices, the skeleton which determined the structure of any substance of the mineral world.

But sometimes scientists are too hasty in establishing laws. A law must involve something stable, indisputable, something that always recurs in nature. If some phenomenon does not recur, or contradicts the rule, it may be too early to claim that a law has been discovered. In this connection scientists have developed a kind of hierarchy. There is such a term as statistic law which refers to the case where some processes recur regularly and certain others do not. If there is no strict regularity at all, we speak of a theory or principle rather than a law. If there are insufficient grounds for a theory or scientific principle, we have to do with a hypothesis, which may

be on the level of scientific fantasy of a more or less grounded assumption.

This hierarchy of relationships is especially apparent in geology. Here are some examples.

By the time of the XVII International Congress of Geologists quite a few laws of mineral formation had been established. One of the most popular at that time was probably the so-called law of the American scientist Emmons who developed the laws of occurrence of minerals in magmatic hearth zones.

By analyzing the crystallization points of various substances, Emmons established the law of temperature zonation of magmatic minerals. It seemed quite clear that the most refractory minerals should crystallize near the magmatic hearths, where the temperatures are sufficiently high, whereas the minerals that can form at comparatively low temperatures should be deposited in the peripheral parts.

This afforded a clearcut theoretical basis for prospecting. Whenever you come across a magmatic hearth you should expect to find near it tin, molybdenum and tungsten, the elements whose minerals "favour" high temperatures. The farther away from this hearth, the higher the probability—for such is the law of temperature zonation—of encountering a different set of elements. And up in the top zone you should find minerals containing lithium and other low-melting substances.

Emmons's law of temperature zonation was gleefully accepted by scientists. It seemed that at last it would bring order to prospecting methods. But after a time reports began to come in

from various countries to the effect that the law of temperature zonation is not always valid, and even that, on the contrary, it is usually inapplicable.

The Soviet Academician S. S. Smirnov attempted to explain this discrepancy. He developed what is known as the pulsation theory, which corresponded to a certain extent to the German scientist G. Berg's idea of the "telescoping" or overthrusting, as it were, of a new set of minerals on an earlier set. It should be pointed out that this theory is not always described correctly.

Essentially, the theory deals with a sort of pulsing of the magmatic hearth which repeatedly flares up and dies down again, to use the terms of Heraclitus. Sometimes the pulsation is strong, and sometimes weak. If it is weak, lithium or some other low-melting element may be deposited next to the refractory tungsten or molybdenum deposited during a previous "flash". On the other hand, during strong magma infusions tungsten and molybdenum minerals may be carried far out from the centre of the magmatic hearth.

The telescoping theory could account for any discrepancy with Emmons's law, but it could show no clear and accurate way of prospecting.

Another example is that of the geosyncline theory, i.e., the theory of folding zones. This theory underwent substantial changes in the course of a few decades. It was put forward by the American scientists Dana and Hall who held that intense sedimentation is occurring in certain parts of the Earth's oceans. To illustrate this law the French scientist E. Haug even left us a drawing showing how large quantities of fragments fall

from the outer zones into the concave middle of the ocean. This "basin" keeps filling up gradually. Later the strata are compressed into folds, faulting occurs, magma is discharged and volcanoes erupt.

I remember how in 1932 the Soviet Academician Dmitry Vasilyevich Nalivkin, speaking against the views of Dana, Hall and Haug, said: "What is this drawing in Prof. Haug's textbook? As an example Haug has taken the Atlantic Ocean and drawn it on a distorted scale. The vertical scale is too large, and the horizontal, too small. The result is a kind of kettle in which sediments fall from the sides into the middle. If any of our students represented the problem like this he would fail, for forgetting that horizontal and vertical scales must be in agreement. But Prof. E. Haug has based his theory on this discrepancy!... If we draw the Atlantic Ocean on its true, undistorted scale, taking its maximum depth to equal one centimetre, the entire width of the ocean on this scale would be no less than 250 metres. Now, if we take into account the curvature of the Earth, its bottom turns out to be convex rather than concave, so that sediments cannot fall from the sides into the centre. Oceanographic expeditions have confirmed that there is very little fragmentary or sedimentary material in the zones of the greatest depressions in the ocean. It hardly accumulates there at all...."

Then is the geosyncline theory scientifically entirely groundless?

Further on Nalivkin agreed that intensive sedimentation is actually observed. But where? Mainly in the coastal and archipelago zones. After

this criticism the predominant conception was that modern geosynclines are situated either in ocean coastal zones or in archipelago zones. For instance, Indonesia, Central America and certain parts of the Mediterranean Sea, particularly the Aegean Sea, are now considered to be typical modern geosynclines.

But here, too, doubts begin to arise. I remember how we sailed for days through the Aegean archipelago region without seeing dry land anywhere on the horizon. We saw nothing but boundless sea.

When you look at the map of the Aegean Sea you do see an archipelago but, in actual fact, the islands are situated very far apart, and there are no major coastal erosions or major sedimentations here as a rule. However, in some parts of the coastal zone of the World Ocean, say, in the estuaries of the Ganges and the Mississippi, very thick beds of sediment are accumulating at present.

Later new facts came to light. We saw that great accumulations were forming in the foothill (or piedmont, as they are called) zones, and so we began to single out piedmont geosynclines. Then, owing to the vagueness of the idea of what a geosyncline is, there appeared very many different interpretations of this term and new derivative terms, such as "eugeosyncline", "miogeosyncline", and many others. There were those who were already beginning to speak of the crisis of the geosyncline theory. For instance, in 1956 Professor V. I. Popov criticized this theory. In his paper "On Certain Ideas in Geology" he wrote that this term had already outgrown itself, and that new forms had to be found to explain observed

phenomena. In short, although the geosyncline theory is accepted at present by most scientists, each group of research workers applies it with their own reservations.

So it happened that a great number of facts accumulated testifying to the existence at present and in the past of areas on the Earth with large quantities of sedimentary rocks in which magmatic processes occurred, followed by mountain building. Facts are abundant, but theory is insufficiently developed. The situation is the same here as in the theory of rock rhythms, where we know the consequences of the process, but have not yet learned its causes.

A very widespread and widely recognized principle at one time was that of actualism (uniformism or analogies). But just when the method of analogies was hailed as a principle, and attempts were being made to extend it to all natural phenomena, its limited nature became apparent. An All-Union Conference was called in 1951 expressly to consider this problem, and geologists came to the conclusion that the actualism method could be employed only to a limited degree, and that it could not be ranked as a principle. Here are some examples supporting this conclusion.

We know that in bygone geological epochs, particularly in the so-called Devonian Period, astoundingly beautiful jaspers formed in very large quantities. These stones are very common in the Urals. One of the world's best deposits of jasper is on the edge of the town of Orsk. Over 200 kinds of this rock have been found there, including varieties with very beautiful patterns. But

the actualism method can throw no light on their origin, because jaspers do not form now.

Another example: Lomonosov concluded from the discovery of a mammoth's bones in Siberia, that the climate had been hot there at some time in the past. He reasoned by analogy, following the method of actualism. Modern elephants inha-it the equatorial zones, or those close to the equator. Lomonosov could not imagine that elephants would be able to live in a zone with a cold climate. He just did not know the difference between elephants and mammoths.

It is not by chance, therefore, that violent opponents to the actualism method have now appeared.The German scientist K. Bulow supports the idea of anactualism, completely denying actualism. He says that the modern period of development of the Earth is exclusive in its history, and that there are processes taking place at present which have never occurred before. Bulow urges geologists to do away entirely with the method of actualism, and holds that conclusions based on this method are wrong.

The truth, as it so often happens, is again somewhere between the two extreme points of view. Statistical laws come into play, showing, essentially, that actualism is applicable in some cases.

We could give many more examples of the insufficient development of theories. At present the absolute age of rocks is studied extensively in geology by analysis of radioactive decay phenomena. The most widely accepted version is the so-called potassium-argon method. It is known that potassium-40 changes in time into

argon-40. Its half-life is a very long one, namely, thirteen hundred million years. Exact estimations of the amount of potassium-40 and its decay product contained in a rock make it possible to calculate how long ago the rock was formed.

It would seem that everything was quite clear and that geologists had at last gained an exact quantitative footing. But the trouble is that the method is based on the idea that the half-life periods of radioactive elements are invariable. But is this so? In 1951 N. S. Boganik, a Soviet scientist, put forward the contention that this idea contradicts the laws of dialectical materialism.

This started a discussion in the press. And such prominent geochemists of our times as I. Y. Starik, I. M. Frank and others were obliged to admit the truth of Boganik's statements. But if we accept this point of view, no calculations of absolute age are possible at all. And so geochemists suggested that geologists employ the radioactive methods of determining absolute age, keeping in mind that when a large number of facts have accumulated, the necessary refinements can be made in the theory.

Indefiniteness often makes geologists put forward daring hypotheses in which they attempt to account for observed facts. Very often these hypotheses verge on scientific fantasy. For example, there has been a great deal of discussion about the problem of what happened in the Tunguss taiga in 1908. And though the event occurred almost sixty years ago, scientists are still arguing as to whether it was a meteorite that fell there or a nuclear explosion, whether the Earth collided with

a cometary nucleus, or the flying body had become so electrified that the collision resulted not in a simple explosion, but in a powerful electric discharge

It has even been suggested that the Earth's atmosphere had been penetrated by a body consisting of antimatter (antiprotons, antineutrons and positrons).

For many years the writer A. Kazantsev insisted that a spaceship from Mars or Venus had fallen in the Tunguss taiga in 1908. Fantasy? But the other hypotheses put forward on this problem are often no more probable. For instance, the meteorite hypothesis has no grounds. Not all the facts fit in with the other hypotheses either. Geologists, geochemists, meteorite investigators, astronomers and physicists carry on debate after debate. Writers, students, school teachers and college lecturers all have their say in the matter. Numerous expeditions have been organized to the district of the Tunguss catastrophe. Some summers scores of people go there, most of them just enthusiasts. They go to the Tunguss taiga on their own during their holidays to help by what little they can in solving this important problem.

Geology is apparently on the threshold of great changes. A vast number of facts have accumulated requiring the development of fundamentally new theories. It was not by chance, therefore, that in 1963 the Soviet scientists V. Belousov and M. Sadovsky suggested a new branch of science—geonomy—which would combine the material and methods of investigation of geology, geophysics and geochemistry.

The shortcomings of the geological sciences, argued these scientists, should be corrected by the mathematical methods which form the basis of geophysics and geochemistry. Numerous hypotheses, statistical laws, principles and methods will then be put on a mathematical footing.

Most scientists were favourably impressed by Belousov and Sadovsky's suggestion; they were well aware that geologists and geophysicists had, as a matter of fact, ceased to understand each other. Hypotheses accepted at present in geology are very often ridiculed by those well versed in mathematics. Generalizations of the experience of mathematicians, geologists, geophysicists and geochemists should be the basis of the new branch of science. After this, perhaps, conditions will be favourable for solving the riddles we now call "laws" in geology.

The Black Arteries of the Depths

At the beginning of 1962 it became known to geologists all over the world that a fountain of Cambrian oil had been struck at the village of Markovo on the River Lena. With its origin dating back more than half a thousand million years, the Cambrian oil found here possessed a number of remarkable features. First of all, it was light in colour, or white, as workers in the oil-industry say. It consisted mainly of gasoline and kerosene with a small admixture of light oils. This petroleum has always been considered the best in the world as regards quality. But even quality

was not the most striking thing about this oil. What was so astounding was that the petroleum occurred in deposits from an epoch when life on Earth was still feebly developed.

True, it had been known before that petroleum occurred in Cambrian and even Pre-Cambrian formations in many parts of the globe. Over 30 fields and more than 200 points are known where Cambrian oil has been discovered either in igneous rocks or in greatly metamorphozed ancient beds.

Such a field was discovered in Morocco. Here oil was struck in Cambrian and Pre-Cambrian shales and granites. In America oil is also found in Cambrian and Pre-Cambrian sediments. Such cases are known in the central provinces of Canada, in the west of Texas and in the south-east of New Mexico.

Still more surprising were observations of the activity of certain volcanoes; Etna in Sicily and Krakatau in Indonesia. Petroleum was discovered in the eruption products of these volcanoes. Traces of petroleum were also found in the products of the Tolima volcano (Central Andes), the Egmont volcano in New Zealand and many others.

So what was so surprising about Cambrian oil being found at the village of Markovo? The thing is that all these facts are completely at odds with the dominating organic theory of the origin of petroleum. What kind of live organisms can there be in volcanoes!

However, it must be said that there are very many hypotheses of the origin of petroleum. Some oil workers hold that petroleum was formed by the

decomposition of dead organisms. Science even has experimental evidence to prove this. A Japanese chemist succeeded in obtaining products greatly resembling petroleum by processing fish in special kettles without access of air. The adherents of this theory claim that some of the oil of the Caspian district could have formed several million years ago after the catastrophic breakthrough of the waters of the Mediterranean into the Black Sea. At that time the Caspian and Black seas merged into a common basin. Oil workers assert that this process of transformation of dead organisms into oil continues to this day.

But the theory of the origin of petroleum from dead animal organisms has many opponents. They say it is not quite clear how the dead organisms could have got buried. The sea depths abound in animals that feed on the corpses of organisms and these scientists do not see how a sufficient amount of organic remains could accumulate on the sea floor to subsequently form petroleum products under altered conditions, without access of air.

Another group of hypotheses contends that petroleum originated from accumulations of plants on dry land as well as in the sea. These hypotheses are also not without experimental evidence. We all remember that during World War II the Germans used an ersatz petroleum obtained from low-grade bituminous and brown coals by subjecting them to the action of steam and temperatures up to 400° C. Under such conditions petroleum products were produced which resembled crude oils so closely that gasoline, kerosene and oil could be distilled from them.

But there are serious objections to this hypothesis also. If it were true one would expect to find oil in the region of any coal field. Such areas have actually been discovered in several parts of the globe, but as a rule oil is found separately from coal.

A third group of scientists put forward the hypothesis of the mixed origin of petroleum, both from animal organisms and from plant remains, but mainly from microorganisms. An adherent of this theory was Academician I. M. Gubkin; he also put forward convincing experimental data to support his views. Academician Zelinsky obtained petroleum products by distilling decayed ooze from Lake Balkhash, formed from dead microorganisms. And Gubkin stated that very many microorganisms and plant remains accumulate in regions round the mouths of large rivers, and in marine zones. The river brings down large amounts of various salts which serve as food for numerous microorganisms. When they die they sink to the bottom and are covered with slime. If this slime then happens to get into a high-temperature zone the conditions are close to those in the experiment carried out by Zelinsky in his laboratory. And the organic substance will yield petroleum.

The age of petroleum is a point of controversy. To some extent this controversy has helped to elucidate the origin of petroleum as well. The adherents of the theory of the formation of oil from organic remains assert that if the age of the petroleum corresponds to that of the host rocks, this is evidence of its organic origin. V. P. Savchenko, an oil geologist, succeeded in developing

a method of determining the age of petroleum by studying the helium formed in it as a result of radioactive decay. He proved that in most cases the age of the petroleum actually corresponds to that of its host rocks.

Very interesting investigations have been carried out by other geochemists too. They discovered drops of petroleum in the delta silt in the estuary of the Mississippi River. The age of this oil, determined by means of atomic time counters, was found to be only 14 thousand years. Hence it was concluded that oil was and still is formed from microorganisms in all geological epochs. It should be pointed out that Academician Gubkin's hypothesis was generally recognized at one time not only in the Soviet Union, but in other countries as well.

But after a while the geologist N. F. Balukhovsky discovered pebbles of asphaltite—weathered petroleum—in the Dnieper-Donets Depression, in the Pavlograd-Petrikeevo District. They occur fairly often in ancient coal deposits over an extensive area more than 200 kilometres long and 20-25 kilometres wide. These pebbles lie beneath relatively recent, so-called Triassic deposits. This means that the age of petroleum is not always the same as that of the host rocks. In this case the petroleum formed before the rocks in which it occurs, and so here Gubkin's hypothesis does not hold.

Sometimes geologists base their hypotheses on utterances of especially authoritative scientists. Such was the case when the points of view of Gubkin and Mendeleyev clashed. Adherents of Gubkin's hypothesis quote Lomonosov, who con-

sidered that oil and mineral coal both unquestionably originated from organic matter. This makes it two against one. But Lomonosov lived two hundred years ago, at the dawn of geology and chemistry, when very little was known about petroleum!

The discovery of oil at Markovo, in strata where traces of life are rare, again threw doubt on Gubkin's hypothesis, which was already commonly accepted. What was the origin of the petroleum in this case?

The news of the Cambrian oil discovery reminded me of our talk with Academician Gubkin at the XVII International Geological Congress. Cubkin then strongly opposed the theory of inorganic origin of petroleum, which had been developed by Dmitry Ivanovich Mendeleyev as far back as 1877. The famous chemist stated that deep below the Earth's surface in the zones with tremendously high temperatures, surprising combinations of certain metals and water may be encountered. Metals contain a certain amount of carbon as an impurity, such as is found in cast iron. When water acts on such a carboniferous metal at high temperatures the carbon combines avidly with the hydrogen in the water and is removed from the metal. The result is a hydrocarbon series. And petroleum is precisely a mixture of various hydrocarbons.

Proceeding from Mendeleyev's hypothesis, oil should be sought in the very depths of the Earth. But down there, below the Earth's crust, there is a certain substance which magmatists imagine as having an enormous temperature and being under a very high pressure. Under such con-

ditions liquid petroleum cannot exist. And then the adherents of Mendeleyev's hypothesis remembered what Otto Yulyevich Schmidt had said in his time. He resolutely opposed the hypothesis of Kant and Laplace concerning the fiery-liquid original state of the Earth. Schmidt held that the Earth, like all the other planets, originated by the accumulation of cold particles. These particles adhered to each other and gradually built up to form the planets of the solar system, but this process could take place only at very low temperatures, not above minus 270-272°. According to Schmidt, the Earth was at first cold, and warmed up gradually, over millions and thousands of millions of years, as a result of radioactive decay. Under such conditions petroleum could have formed "after Mendeleyev". And possibly the Markovo well was a confirmation of the hypotheses of Mendeleyev and Schmidt.

Astronomical data is curious in this connection. In studying the spectra of the planets astronomers discovered an abundance of hydrocarbons on Jupiter, Saturn and other large planets. Recently a luminescence of rocks was discovered on the Moon, caused by ultraviolet irradiation. Such luminescence can arise only in the presence of either rare elements or petroleum bitumens. The study of meteorites yielded even more interesting data, it being found that they contained fairly large quantities of hydrocarbons. One of the Russian scientists, V. D. Sokolov, said that petroleum originated in outer space. On the basis of Sokolov's statements, Professor N. A. Kudryavtsev, one of his followers, assumed that petroleum originates in the vicinity of magmatic hearths

(and that is how petroleum got into volcanic eruptions!).

And here it occurred to me: maybe Sokolov or Kudryavtsev had been with us at the XVII International Geological Congress and it was one of them that spoke out contradicting Gubkin's hypothesis?

Looking over the list of the participants of the Congress, I found five Sokolovs and one Kudryavtsev. But a disappointment was in store for me. Sokolov put forward his hypothesis as far back as 1892, and could hardly have been among us young geologists discussing the problem at the Congress in 1937. However, Kudryavtsev probably could have been there. But whether it was the same Kudryavtsev, and whether he had been with us, I was unable to ascertain.

Be that as it may, the hypothesis of the inorganic origin of petroleum now opens out new horizons before us. Maybe there exist in the depths of our planet certain reservoirs communicating with the surface zones through channels of some kind. Maybe these channels, the black arteries of the depths, are the faults located in the zone of Gondwana and at many other points on our planet? It appears that the Hurghada, Ras-Harib, Belaim and other oil fields of the U.A.R. are located precisely along the line of faulting near the Red Sea in the region of the Suez Canal. We could also mention a number of oil fields within the precincts of the Rhine and in the Baia faulting district of South America.

Thus, if oil is a product of the depths, we must drill for it as deep as possible. Perhaps at a great depth we shall encounter solid petroleum under

great pressure? Perhaps in the depths we shall find inconceivable reserves and accumulations of oil that we never even dreamed of. I. M. Gubkin's hypothesis indeed warrants reconsideration: is everything in it quite true?

What the Neoneptunists Say

A great deal has been said of the destructive geological work of the sea surf. This subject has even attracted poets.

Here is how the Russian poet F. I. Tyutchev described the unceasing action of the sea:

> Raging, billows skyward streaming,
> Ceaselessly, the ocean surf,
> Roaring, whistling, howling, screaming,
> Beats against the coastal bluff....

Anyone can see that the result will be the destruction of the coast. Gigantic ocean waves shake the globe. The impact of these waves is such that a storm in the Bay of Biscay can be registered by the seismic station in Moscow. Even an ordinary wave about six metres high and 80 to 100 metres long develops 250 horse power. Many other examples could be cited, and they all bear evidence to the fact that even the strongest rocks finally collapse under the action of the waves; the onslaught of the sea crushes them and reduces them to sand, clay and slime. The sand is then caught up by the outgoing waves and carried out to the open sea, where it sinks to the bottom.

But the action of the waves is not the only

means of forming marine sediments. Several years ago, in his travel notes about a trip to one of the Congresses in South America, the geographer Academician I. P. Gerasimov described his flight across the Sahara. He was headed, he wrote, for the Atlantic Ocean which he was to cross and then land in Buenos Aires. Up where he was, nine thousand metres above the Earth's surface, the sun was shining. The temperature outside was 35° below zero, but down below a simoom was raging. Clouds of dust and sand caught up by the whirlwind rose to a height of five thousand metres and rushed onwards at a terrific hurricane rate. This sand and dust was carried far beyond the limits of the Sahara, and could be seen to settle gradually into the Atlantic Ocean.

A great deal of silt is brought down by rivers, melting glaciers and especially icebergs. Also, the crystallization and deposition of salts is a constant source of sediment on the ocean floor.

In the 18ht-19th centuries little was known about the oceans and what goes on at the bottom. It is quite natural, therefore, that there appeared in those years a rather singular trend in geology called neptunism after Neptune, the sea god. One of the greatest neptunists of the 18th century, the German scientist Gottlob Werner, started the so-called basalt discussion, which continued with varying success for many decades.

Gottlob Werner's idea was a simple one. He disagreed with the investigators Ardonineau and Dolomieu who asserted that basalts, or basic rocks, are frozen volcanic lava. In his brilliant lectures Werner contended that basalts have noth-

ing in common with volcanoes, but that they originated as a result of crystallization of sediments at the bottom of the sea.

Whether Werner's arguments were so convincing that he enthralled the majority of scientists, or whether mankind had not yet acquired enough knowledge on the question, Werner's views were current for 35 years. Even after the ideas of the volcanists were finally established in science, there were still enthusiasts who supported Werner's hypothesis. Among his defenders was one whom any geologist might envy. The great Johann Wolfgang Goethe shared the standpoint of the neptunists to the last days of his life. In 1796 Goethe wrote in his *Xenilu*: "Poor, poor cliffs. You must bow down to fire, though no one ever saw you born of fire." And it was none other but Goethe who exclaimed: "Let it be known to posterity that there lived at least one man in our time who saw through the absurdity of the plutonists."

It is hardly necessary to relate the history of the struggle between the neptunists and plutonists (volcanists). After the igneous origin of basic rocks—basalts—was proved it seemed that the neptunists had finally been defeated. And indeed, nothing was heard of them throughout almost the entire 19th century. However, at the end of the last century, and especially in the present century, the ideas of the neptunists revived, though on a new footing. By then scientists had learned the laws of sedimentation on the sea floor. Oceanographic expeditions had established the types of sediment that accumulate at various parts of the ocean bottom. It was found that very

fine slimes deposit at great depths, while psephitic (coarse fragmental) or fragmental material accumulates in the coastal zones or near the shore. In the zones close to the equator, and at the bottom of warm seas in general, carbonate ooze accumulates, which contains a large amount of lime. Salts concentrate in gulfs and lagoons.

It is not by chance, therefore, that a satirical picture once appeared in an American Scientific magazine showing an academician hopelessly muddled up among Neptune, Vulcan and Pluto. Not knowing which god to worship he drifts about rudderless in an ocean of magma.

The ideas of the neptunists came back to life after geologists began to study the processes of metamorphism of rocks, that is, changes that take place after they have formed. Now, what happens to a rock if it is heated to very high temperatures? What happens when it is subjected to pressure, or when it is permeated with steam carrying various salts?

Visitors are always greatly impressed by the rock specimens on display at the Sverdlovsk Mining Institute. Here is a description of some of them. A lump of magnetic iron ore broken off while blasting rock at the Vysokogorsk Iron Mine near Nizhny Tagil was found on examination to bear the impression of a marine mollusc of the so-called gastropoda snail class. Before this discovery it was thought that the iron ores of Mt. Vysokaya were of magmatic origin. But how could a mollusc exist in magma? There must be something wrong.

Or here is another case. Corals, and shells of other marine molluscs resembling ordinary river

bivalves of the Pelecypoda class were found in a deep pit at the Sibai copper mine in the South Urals.

Molluscs and corals in copper ore? But we cannot even imagine copper ore falling directly out of sediments or mollusc shells consisting of copper ore!

Seals' bones are very often found in Kerch iron ore; these seals found their grave at the bottom of the sea, among iron ores. However, these bones do not consist of the usual calcium and phosphorus compounds, but of the same substance as the Kerch iron ores. Could it possibly be that seals with iron bones swam about in the past in the Black Sea?

Thus, nature herself gradually began to reveal her mysteries. She told us that rocks live a wonderful life, full of mysterious transformations. During their lifetime they pass through a complex and fascinating history.

Take, for instance, the history of sea ooze. After accumulating it does not remain the same, but loses water and turns into limestone. Subjected to the high temperatures near a magmatic hearth the limestone recrystallizes and becomes marble. Resplendently beautiful marbles can be seen today in the underground palaces of the Moscow, Leningrad and Kiev metros. They contain the remains of organisms that lived when the marble was still ooze.

Sometimes in the vicinity of magmatic hearths limestones give rise to exquisitely beautiful minerals and rocks. For example, lazurite, a mineral of very complex composition with an intense blue ultramarine colour, once formed in the Trans-

Baikal. The conditions of its formation resembled those of marble, but in this case the magmatic hearth in contact with the limestone had a slightly different chemical composition, and its vapours penetrated the marble, creating the inimitable beauty of its rich blue colour.

Under other conditions the life of the rock leads to the formation of other minerals. If we ascend from the great depths to the surface zones where oxygen is dissolved in the subsoil water, we find that here, especially above copper deposits, copper is oxidized and becomes enriched not only in oxygen but in carbon as well. This compound of copper with carbonic acid also creates a beautiful rock called malachite. Different proportions of the solutions, with varying concentrations, give rise to the magical patterns we admire so much on polished malachite surfaces.

Thousands of fascinating stories could be told about the formation of different rocks and minerals under various thermodynamic conditions. But we shall confine ourselves for the time being to simple clayey sand, under experimental conditions. If we take pulverized feldspar, which makes up a considerable part of arkose sand, and subject it to a pressure of five thousand atmospheres, it would seem that it should be comminuted still more. But no, fine albite (feldspar) crystals grow in it. Now if the pressure is raised to 10 thousand atmospheres, these crystals are still not comminuted but, on the contrary, become larger. Suppose that at a certain depth, in the pressure zone, feldspar crystals begin to grow among quartz grains occurring together with clayey sand. There may

also be an admixture of mica flakes there. Under such conditions a massive rock forms consisting of quartz, feldspar and mica. And we know that ordinary granites consist of these minerals.

It is said that granite is an acid rock found in the magmatic hearth feeding a volcano of extraordinary eruptive power, of the type of Bezymyannaya on the Kamchatka Peninsula. But it appears that we can make the same acid rock without melting, by subjecting clayey sand to pressure.

So present-day neptunists assert that magma and volcanic activity are but minor episodes in the life of our Earth, and that most rocks originated from the metamorphism (transformation) or regeneration of rocks.

The neoneptunist-transformists attach a great deal of importance to the penetration of water and water vapour through rocks. This water dissolves some of the minerals and carries them away from their original habitation, while the next portion of steam and water may bring in other salts with them.

For example, the molluscs found near Mt. Vysokaya and Sibai had shells which had originally consisted of calcite. But later the chemical compounds constituting the mineral of the shell were dissolved and carried off, and their place was taken by iron ore in the one case and copper ore in the other. These minerals were brought in from outside and substituted the entire initial substance of the mollusc's body. This process proceeded so delicately that the finest sculptural details which ornamented the shell remained intact.

Of course, not everything here is indisputable. Magmatists also admit that some metals can be substituted by others. But they assert that the final stage in the life of a frozen magmatic hearth is the activity of water vapours and of water itself which appears in it at this time. The magmatists hold that these hot solutions penetrate into the Earth's crust from below, from the Earth's mantle, carrying with them the riches of the magmatic hearths.

Neoneptunists, on the other hand, claim that solutions may come not only from the mantle or from zones of magmatic hearths. For instance, it has now been established that at a depth of about two kilometres below the West Siberian lowland, there lies an ocean of boiling water, covering an area of three million square kilometres. The water flows there through porous rocks, filling all the large and small holes in them. It moves mainly horizontally, in conformance with definite laws. You can imagine what boiling water under high pressure can do at those depths! It is able to carry off from the dissolution zone all kinds of salts, and subsequently brings in new amounts of dissolved substances.

Taking into account all these phenomena, the neoneptunists keep consolidating their stand from year to year. Basalt, or rather, basalt-like rocks are now known in which organic remains have been discovered. Possibly, the basalt discussion started by Werner in the 18th century may come up again on the basis of the achievements of modern science. The last word has not yet been said.

That is why I keep recalling the opening episode

of this book: the banquet before the XVII International Congress, and the argument between the young geologists. There is a great deal known now about the life of rocks that was not known then. It is a good thing that such a great scientist as Academician Vernadsky warned us that not everything in nature was as simple as we thought. Vernadsky already at that time spoke of the cold state of the inner zones of the Earth. By his ingenious scientific foresight he brought us closer to the methods of rock formation that we are beginning to understand only now.

"We Must Not Wait for Favours..."

Primeval man never stopped to think how to utilize the wealth around him to best advantage. Only in the later stages of his development did he begin to take measures to put in supplies of food, tools and raw materials.

Mankind is now on the threshold of preparing artificial protein, and of producing at special factories what we now cultivate in the fields.

And what about the utilization of mineral resources? In this case also he at first made use only of what happened to come his way. There were very many deposits of mineral raw materials that cropped right out on to the surface. Gold, native copper, tin or its ores, sometimes even precious stones could be found right on the ground. The first emerald finds in the Urals

were made among the roots of a torn-up tree, and how common are similar cases in the history of mining!

Then the time of lucky finds ended. Man began to dig into the Earth to search for the minerals he needed, but still the element of chance predominated. And only with the development of economics did geologists begin to reckon up resources, and to take stock of mineral raw materials. Supplies of various kinds of economic minerals have been estimated and lie in store in the underground vaults of each country. Data on the mineral resources of the country, their amounts and where they were discovered are kept at special geological bureaus. If the country is short of any particular kind of raw material, the geological bureau has data indicating where it can be imported from.

But the demand for raw materials continues to grow. And so there appeared the idea of compiling special maps by which the discovery of mineral deposits could be foreseen and planned. Not all these forecasts, it is true, are quite accurate, but such maps have already been compiled for some minerals.

But this did not quite solve the problem. Minerals are not always available in sufficient quantities. And soon ideas began to nature concerning the creation of artificial (synthetic) kinds of mineral raw materials. Take, for instance, diamond. It is found in nature very rarely, and wherever it is found the diamond content per cubic metre of rock is extremely low. Sometimes it is necessary to crush, wash and X-ray a tremendous quantity of rock before a single small diamond is found.

But what if we use another method and make diamonds artificially?

In recent years the synthesis of diamonds has been accomplished in the U.S.S.R. Soviet industry is now supplied with all the diamonds it needs, most of them synthetic. Without diamonds modern industry would be greatly handicapped. Economists have reckoned that if the U.S.A. were deprived of its diamonds the industrial potential of the country would be several times lower than it is.

But are diamonds the only kind of raw material that can be made artificially? Of course, not. These days very many different ways of reproducing or concentrating mineral resources are being developed. Many minerals are confined to, or rather, distributed in various rocks. For example, all the elements of Mendeleyev's Periodic System are present in granite and the rocks associated with it. But in most cases they are there in such small amounts that there is no sense even in speaking about their extraction.

It is known that all the elements of the Periodic Table are found in the waters of the seas and oceans, even gold. If, say, we counted up the amount of gold carried annually into the Caspian Sea by the Volga, the result would be quite breathtaking. According to the data of D. Bilienkin there is $^1/_4$ milligram of gold in each cubic metre of river water. The Volga empties about 250 cubic kilometres of water into the Caspian each year, thus throwing over 600 tons of gold out into the sea! The significance of this amount can be understood from the fact that at the end of the 19th

century the gold production of Tsarist Russia totalled about 30-35 tons annually.

Here, indeed, is a miser giant trembling over his gold! And if special traps were set up in the delta of the Volga a considerable part of this gold could be recovered. Such traps could be placed on all large and small rivers. This would be sufficient to bring the country unheard-of quantities of gold. And if we take into account the concentration of various metals not only in river and sea water, but in subsoil waters as well, the possibilities that arise before us are quite inexhaustible.

There are other ways, too.

Metallurgists know that when working with tin there often occurs a phenomenon referred to as "tin disease". All objects made of this metal decay, turning into a grey powder. Metallurgists have established that this is due to one modification of tin changing into the other. At temperatures below 130 degrees white tin changes into grey tin, greatly decreasing in volume thereby. To restore the former properties and crystal structrure to the tin the powder has to be remelted.

The same, or rather a similar phenomenon is observed in the world of rocks.

There are many folk stories about werewolves. The Russian legend has it that to change a man into a wolf or some other animal it is sufficient to put a bast belt around his waist and utter the appropriate invocation for the occasion. There are few people now who seriously believe in such transformations, but in the past many incomprehensible phenomena were attributed to werewolves and sorcerers.

"Werewolf-stones" are quite a common phenomenon in mineralogy. The present author has quite a number of such stones in his personal collection.

For instance, there is a stone resembling quartz or rock crystal in shape, but when you take hold of it you find that it is very heavy. Test it with a knife, and you find that it scratches easily, while quartz itself can scratch steel!

On closer examination you find that this stone easily leaves a trace on paper. That means its hardness is very low. Chemical analysis and a number of other properties show it to be ordinary galena, lead glance, which has assumed the shape of quartz. A real werewolf-stone!

This werewolf-stone had a strange history before it acquired its present shape. As a result of complex chemical action lead ore replaced the quartz. Thus, processes occurred in nature which resulted in the dissolution of the splendidly formed quartz crystals by chemically active waters, which carried them away from the place of their birth. Galena, brought in by some other pulsating aqueous solutions, formed in their place.

These pulsating aqueous solutions needed a place to crystallize out. But as there was no unoccupied place, in their struggle for "vital space" they took that which had formerly belonged to quartz.

Very many similar struggles for vital space take place in the world of rocks. The behaviour of sericite, a mineral very close or even identical to white mica or muscovite, is especially instructive. The only difference between the two is

that while sericite consists of minute flakes, discernable sometimes only under a microscope, muscovite, which is lighter in colour, more transparent and denser, occurs as well-faceted slightly exfoliated crystals.

A very interesting paper was published in Doklady Akademii Nauk SSSR (Reports of the U.S.S.R. Academy of Sciences) in 1962 by P. Y. Yarosh, a research worker of the Urals Branch of the Academy of Sciences, in which he writes about his observations of the behaviour of sericite in the Urals copper belt. Here sericite plays the part of a werewolf-rock, an aggressor-rock. It can be seen quite clearly under the microscope how sericite corrodes ore crystals. It penetrates the minutest cracks and the tiniest pores in the quartz and passes into the zone of development of the ore mass, where it occupies the space formerly occupied by ore. It would seem that sericite had nothing to gain here. The formula of the mineral contains many elements, but the most important of them are aluminium, silicon and potassium. The presence of potassium makes the medium very alkaline and corrosive. To build up its atomic skeleton sericite needs a lot of aluminium, oxygen and silicon. This chemical composition accounts for the fact that sericite very often takes root in spaces which were occupied earlier by feldspars, topaz, beryl, garnet and many other minerals containing aluminium, oxygen and silicon.

There is a precious mineral which is dear to the heart of any jeweller. It is called "star sapphire". A bright inner lustre suddenly appears in blue sapphire. You turn the faces of the stone and

a spark of light flashes in it, seemingly independent of the light of the surrounding rays.

For a long time people wondered about the cause of the starriness of sapphire; then by microscopic investigation it was established that the stone contains flakes of foreign inclusions, mainly sericite, which have begun to corrode and spoil the precious sapphire.

If the process continued nothing would be left of the sapphire, and the owner of the jewel would suddenly discover only a few flakes of sericite. But the process was stopped by something, and therefore only a small particle of the aggressive mica remains caught inside the crystal. It is this that causes the magnificent play of light, the splendid star-like gleaming inside the crystal.

It is easy to understand sericite corroding substances in which it has something to "feed" on, but it has nothnig to gain in pyrite and chalcopyrite, the minerals making up the orebodies of copper deposits. They contain only iron and sulphur which this mineral does not need to build its atomic skeleton. The explanation here is a different one.

Sericite is "attracted" to the zones of pyrite deposits by the ease with which the ore can be removed. That is why sericite so quickly fills the space that is freed when the copper ore is destroyed.

And now we might ask whether this process could be reversed somehow. Could we not dissolve the sericite, remove it from the zone it has occupied, bring in ore solutions and restore the copper deposit? At present, of course, this is utopian;

it is not even science fiction. Nobody has yet taken this question up seriously. But the time will come when such problems are posed.

When reconstructing the course of the natural processes we must consider whether the ore solutions circulate horizontally or vertically.

If we take into account only horizontal circulation or flow of solutions from the upper layers, we must proceed from the hypotheses of the neoneptunist-transformists. Then we should be interested in the subsoil waters of the upper part of the Earth's crust.

But if we recognize the theory of vertical circulation of solutions coming up from below, we inevitably arrive at the necessity of studying the subcrust parts, i.e., the mantle of the Earth.

And again we come up against the same old question: "What is the mantle?".

Flow of Information

A Signal into the Unknown

A very long time ago, in my youth, I had occasion to go to the Timan mountain range, in the upper reaches of the Mezen River. I had often been there before too. During my geological expeditions I often met hunters and anglers, who taught me a great deal.

I was especially fond of hunting for fish. No, that was not a slip of the tongue; I meant precisely hunting. When the polar day ends in the North, and night begins to fall, hunters strike a "ray" in the bow of a boat, meaning that they light a fire of dry twigs or heather on a special iron fluke or "goat" as they call it. The hunter stands in the bow of the boat with a fish-spear in his hands while his helper poles the boat along standing in the stern. The hunter scans the depths illuminated by the "ray". Suddenly he spies a pike, motionless like a log. His spear flashes out, and the next moment the fish is in the boat. Then a large fish rushes past the boat at a terrific speed. The hunter throws his spear, and in a twinkling it is floating vertically up the river rocking to and from. The hunter is lucky; he has bagged a 15-kilogram salmon.

The first time a hunter gave me a spear and told me to hit a dead fish lying about one and a half metres below the surface, I had to throw it about thirty times before I made the hit. This was not only due to lack of skill. It was just that I did not make allowance for the laws of refraction of light. In my excitement I had forgotten the simple law of physics that in passing from one medium into another a light ray is refracted.

Seismic waves, the signals we send into the depths of the Earth from the surface, are refracted and reflected inside the Earth in exactly the same way. How are these waves sent?

This conjures up a picture in my mind. I remember, during the war years, how once I went to watch a diamond deposit being prospected in the Chusovaya River basin. The prospectors included not only geologists, but geophysicists as well. I was especially struck by one of the crews; an engineer accompanied by about a dozen barefoot boys about eleven or twelve years of age. I asked the geophysicist: "What's this, an excursion?" "No," he said, "these are my workers. There's a war on, you know, and you can't get grownup men now."

The boys carried a heavy sledge hammer in turns.

"And what's this for?" I inquired.

"You see," replied the geophysicist apologetically, "it's war time, and explosives are not to be had. But we've got to send signals down to locate the placer boundary by the refracted and reflected vibrations...."

I joined this rather unusual crew and went out prospecting for diamonds with them.

When we came to the prospecting line the strongest boy took his stand with the sledge hammer in his hands at one of the points. Nearby so-called seismic pick-ups, devices for registering all shudders of the Earth, were buried at definite intervals. At the geophysicist's command the boy's hammer "operated" and a dull thud was heard. Seismic waves, vibrations of the soil spread in all directions from the point where the hammer struck. These waves went through the diamond placer and entered the underlying bedrock. Some of the waves went on further, gradually dying away, but some of them were reflected from the placer bed, returned and were registered by the seismic pick-ups. The time it took the seismic waves to pass through the entire placer was also recorded. When the seismogram was decoded they could tell over how many metres the placer extended. Then, from the average diamond content in it, there was no difficulty in calculating the approximate amount of precious stones contained in the whole area. A very complex job was being done by super-simple means. I wondered once again at the inventiveness of the human mind. But this was in the war years, when neither workers nor explosives were available. And how do geophysicists work in normal conditions?

In 1958 the miners working at the iron mine in the outskirts of the town of Pokrovsk-Uralsky finally resolved to eliminate a hazard which had become a constant threat. Above the mine flowed the River Kolonga, and its water kept seeping through into the mine workings. It was not easy to work at the "wet faces". Even special waterproof suits were of little use. And so the

miners suggested diverting the waters of the Kolonga by making a new channel for them, and thus "drying" the face.

Calculations showed that this would require a whole system of holes to be drilled, charged and blasted to throw up the rock.

Such a powerful blast had never been detonated before in the Soviet Union. Naturally, everybody interested in such an unusual event, primarily geophysicists, gathered together at Pokrovsk-Uralsky. But in keeping with safety regulations the entire blasting area was cordoned off. The train I came up in probably had fewer passengers on board than militiamen, sent in from Sverdlovsk and its suburbs to form the cordon.

A hill about three kilometres distant from the place of the explosion was put at the disposal of experts and sightseers. According to the calculations of the miners and blasting safety experts, no fragments could come this far. Cameramen fussed with their apparatus. We got our cameras ready, and took advice from the moviemen about shutter speed and aperture. The newspaper reporter from the Sverdlovsk *Uralsky rabochy* (*Urals Worker*) was obviously agitated, and finally climbed up a tree to see better.

At last we heard the warning siren. We knew that the command would be given in a few moments. The shot was scheduled for 2 p. m., March 25. Finally, the warning rockets went up. The head of the operation shouted "Fire!" and a thunderclap crashed through the air....

If you watch an explosion through a "time lens", by photographing it with a medium-speed cine camera at one thousand frames per second,

you can see its successive stages. This explosion was stretched out over 170 milliseconds. This so-called millisecond delay blast cushioned the shock, so that all the buildings in the settlement remained intact.

During the first millisecond the charge in the hole with the primer was fired. This hole was connected by detonating fuse to the rest of the charges and touched them off. To us observers all the charges merged into a single concussion, a blinding flash and a deafening crash. We all staggered back under the impact, but immediately afterwards a cry of admiration escaped our lips. A dome of smoke, fire and rock fragments shot skywards to a height of 300 or 400 metres, and kept rising higher and higher. The centre was crowned with an immense column of smoke from the largest, 152-ton charge. Then the smoke and dust began slowly to subside and lost its dome-like shape. A mild wind blew it towards the settlement.

The explosion was watched not only by human eyes and camera lenses. Special seismic stations situated far from the explosion zone were also on the alert.

Every artificial earthquake-explosion is of great interest because by arranging seismic stations appropriately during such an explosion information about the nature of the rocks in the vicinity can be obtained wherever necessary. The explosion at Pokrovsk-Uralsky made it possible to elucidate the geological structure of sections of the Urals which at that time were insufficiently known. It was a signal into unexplored regions.

The point is that the waves spreading from an explosion or an earthquake centre pass through different rocks at different rates. As the waves are repeatedly refracted and reflected on their way, they arrive at the observation point at different times. This property was utilized by geophysicists to determine the type of rocks the wave passed through, the thickness of their layers and their properties.

A radio signal was transmitted from the command station, and the recording systems of the seismic pick-ups were switched on. The first waves took about a minute to reach Sverdlovsk, and then other refracted and reflected waves of various intensities came "hustling" after. Eight special seismic stations were set up in various parts of the Urals, the Urals foothills and the Trans-Urals. Besides this, all the seismic stations in the Soviet Union received signals from Pokrovsk-Uralsky.

For over an hour we waited for the trench to clear of fumes and for the safety service to inspect it for possible misfires. Finally, on receiving the "All clear" signal we rushed to the site of the explosion to see the result. It was impressive. Trees were stripped bare, broken and uprooted within a radius of about 80 metres around each hole. On the snow lay large pieces of rock, some of them weighing hundreds of tons. These were fragments of strong cliff rocks, porphyrites, and ancient solidified lava. For 350 or 400 million years this lava with inclusions of "volcanic bombs" had rested peacefully in the Earth. And now the bombs had again risen into the air and fanned out around the explosion zone.

Over 700 thousand cubic metres of rock had been lifted up and thrown over a great distance. The result was a ditch 1,100 metres long, up to 33 metres deep and up to 120 metres wide. It was through this ditch that the waters of the Kolonga flowed when the river channel was dammed up.

After the explosion there began a period of painstaking work for the scientists: all the records of the seismic stations had to be collected and studied very carefully. The Pokrovsk-Uralsky and the famous Korkino explosions made it possible to establish the thickness of the Earth's crust in the Urals. It was found to be 38 kilometres thick and to consist of four layers 10, 7, 12 and 9 kilometres thick. Thus signals into the unknown, repeatedly refracted and reflected, once more helped us to solve some of the mysteries of the structure of the Earth's crust. Observations of all the shudderings of the Earth, both natural and artificially caused, are gradually revealing the general structural pattern of the part of our planet we call the Earth's crust.

As a matter of fact, the term "Earth's crust" is not quite right. It arose in the past when scientists thought the Earth had originated from a molten mass and then, cooling gradually, had become covered with a crust. Nowadays most astronomers and geologists are of a different opinion, but the term, though not true to fact, has persisted in the literature. Nor is this the only case of its kind. We have many terms that had a certain sense when they arose, and then became habitual and persisted. So let it be the Earth's crust. This part of the planet has to be called something!

Numerous investigations of the Earth's crust have established that on almost all continents it is 40, 50 or 60 kilometres thick.

The adherents of the so-called isostasy theory assert that the continents are made up of relatively light rocks, while heavy ones constitute the ocean floors. Owing to the existence of a definite mass equilibrium, the lighter sections keep rising upwards over a long period. They then disintegrate in the surface zones. The decayed material is then carried down into the ocean depressions, into the zones of heavy rocks. The ocean floor keeps subsiding deeper and deeper into the Earth's mantle. It is this compensation of light and heavy masses, say the adherents of the isostasy hypothesis, that constitutes the life of the Earth's crust.

It must be said that if everything were really as the adherents of this hypothesis put it, the continents would keep rising endlessly. They would disintegrate, and then the complex of rocks that constitutes the Earth's mantle would appear on the surface. Thus, the validity of this hypothesis is rather doubtful. The Earth's crust on the continents is not monolithic, but is parcelled off in strata. The top stratum is made up of sediments which formed either at the bottom of the sea or under conditions of continental accumulation of fragmentary material. This sedimentary layer varies in thickness. In the European part of the U.S.S.R. it is up to three kilometres thick. On the average, or rather, over a considerable area, its thickness is about one and a half kilometres. But there are places where it gradually thins out and disappears.

Here the denser material of the second layer

comes out on the surface. As a rule it consists of rocks mainly of a granitic composition. And that is what it is called—the granitic layer.

In the Urals, on the Kola Peninsula and in Karelia the granitic layer comes very close to the surface; it can be found over considerable areas of the Ukraine. And beneath the sedimentary rocks it has been detected by deep drill-holes over the entire territory of the European part of the U.S.S.R.

Still deeper, in the bottom part of the Earth's crust, lie denser rocks. Judging by the rate of propagation of seismic waves through them, they greatly resemble basic, basaltic rocks. It has become generally accepted in the literature that the granites are underlain by basaltic layers.

For some reason the boundary between the sedimentary rocks and granites has not been named. As to the second boundary, that between the granitic and basaltic layers, it is often referred to as the Konrad discontinuity, after the German scientist who described it in detail. And the lower boundary of the basalts separating the Earth's crust from the deep-seated layers of our planet is called the "Mohorovičić discontinuity" or "Moho discontinuity" for short, after the famous Yugoslav scientist.

Below the "Moho discontinuity" seismic rays rush into the depths of the planet at sharply increasing speeds.

These three boundary lines marking the three layers of the Earth's crust are observed everywhere on all the continents.

In the zones of the ocean floor, especially in some parts of the Pacific or Atlantic Ocean, the

thickness of the Earth's crust decreases pronouncedly over a considerable area. In some parts of the Pacific Ocean the thickness of the Earth's crust is only five or six kilometres, covered by a thick layer of water. Here the sedimentary layer is insignificant, sometimes not more than a few tens of metres thick, and there is no granitic layer at all. Then comes the basaltic layer.

By analogy with the rocks we know on the Earth's surface, a peridotite layer is distinguished beneath the basaltic layer, this being already in the zone of the Earth's mantle. Peridotite is a very dense, very heavy ultrabasic rock with a minimum silica content. The velocity of seismic waves increases pronouncedly in it.

And so, at a depth of 40-60 kilometres below the continents and 5-10 kilometres below the floor of the oceans lies that mysterious substance which many attempt to compare with peridotitic ultrabasic magma, the forefather of all rocks born of fiery liquid melts.

But maybe the analogy with peridotite is very superficial, in the literal as well as the figurative sense. We know nothing about this substance except the rate of wave propagation through it, which increases everywhere, in all parts of the globe.

A terrible catastrophe occurred in the southern part of South America not long ago. The people of Chile suffered an incredible disaster. An earthquake broke out in May 1960, and in the course of only four days over four thousand persons were lost or killed, and over two million made homeless.

The first devastating shock made itself felt in

that country on May 21, 1960, and then it was followed by a series of still stronger shocks alternating with weaker ones.

All this time an alarming drumming could be heard day and night in the mountains in the Temuco district inhabited by Indian tribes. It was the local people praying to their gods for mercy. But the gods were silent. The beating of the drums was drowned by an inconceivably loud rumble that came from under the ground, and then mushroom-shaped pillars of smoke and ash shot up into the sky in several places at once. It was the simultaneous eruption of 14 volcanoes.

At the same time in the coastal zone the underground shocks raised huge sea waves. The whole town of Puerto Saavedra disappeared in one minute. It was simply washed away by an ocean wave.

The sea waves did not confine themselves to Chilean territory. They went tearing across the whole Pacific Ocean at a rate of over 650-700 kilometres per hour. A day later, having covered about 15 thousand kilometres, the waves came down on the coast of the Far East where they caused incalculable disaster to the Japanese people. Waves more than ten metres high destroyed everything in the coastal zone. Alarm signals and tragic reports began to come in from many towns and villages of Japan.

The coast of the Soviet Union, and some of the settlements and towns in other parts of Eastern Asia did not suffer great damage. The Warning Service was on the alert in good time, and the entire population of the coastal regions was notified and was able to get away to safety in time.

The workers of the Warning Service knew that it was a tsunami coming—a huge wave of shattering force. In the past hundred years about 350 such waves have swept across the Pacific Ocean, always caused by a strong tremor of the ocean floor. Gradually people have learned, if not to fight tsunami, to prevent the unnecessary and senseless casualties that occur during such catastrophes. Soviet scientists have compiled a tsunami atlas by means of which the speed, height and destructive force of the wave can be calculated in an instant.

Meanwhile, in Chile the tragedy continued. Whole districts of the cities of Valdivia, Concepción and many others were razed to the ground.

Here is the description given by a reporter of the newspaper *El Mercurio* who flew over the zone of earthquakes and volcanoes during the catastrophe. Near Mt. Puntaguda he saw a huge ash-grey cloud streaked with crimson lines of fire. It resembled an enormous storm cloud, but when the observers went closer they saw that they were witnessing the birth of a new volcano. It could be seen that the cloud consisted of puffs of ash and smoke pouring forth from several volcanic funnels. Some of the volcanoes were wrapped in steam rising from the hot waters of geysers. From time to time powerful electric discharges could be seen striking through the clouds and the air down below, under the wing of the aeroplane. The catastrophe grew worse.

During the shocks the relief of many parts of the country changed. Islands disappeared, and new elevations rose. The force of the impact reached a fantastic strength. It has been reckoned

that the Dnieper Hydropower station would have to operate for 150 years without stopping to produce the same power. And here it all came out in an instant!

No wonder the whole Earth was shaken by this huge eruption of energy. The earthquake signals not only passed over the land and sea, but also travelled into the depths, piercing the Earth's mantle and core and emerging again at the surface of the planet, where they were registered by many stations on the globe.

On the day the earthquake started, May 21, 1960, the shocks and Earth tremors were recorded, in particular, by the station in Moscow. The signal arrived here in 16 minutes. From the first shock Moscow, like other stations the world over, kept the Chilean catastrophe under close observation. At the moment of the strongest shocks the ground in Moscow shifted as much as one and a half millimetres. This was a sign of a catastrophic earthquake.

Over one hundred thousand earthquakes of varying strength are registered each year by the seismic stations on Earth. In order to evaluate the strength of earthquakes seismologists have worked out a twelve-grade scale which can be divided into several groups.

The first group embraces the first three grades. They are called weak or imperceptible Earth tremors. These signals are perceived easily by some animals. For instance, cats' fur stands on end. Most domestic animals become restless, and birds fly away from the place of the earthquake.

It must be said that second- and third-grade tremors of the ground are also felt by many

nervous people. Once I witnessed an unusual sight at a Crimean neuropathological sanatorium where I happened to be a patient. Suddenly one night a grade three earthquake began. None of the patients, including myself, felt anything. The only ones who ran outside were the doctors and the other medical personnel. It turned out that they were the most nervous people in the sanatorium!...

The second group includes the medium earthquakes of grades four, five and six. These shocks are felt by everybody. An example is the Earth tremor in the Central Urals that took place in what was called Yekaterinburg (now Sverdlovsk), Chelyabinsk and Perm in 1914. The strength of the earthquake was up to the sixth grade. Many inhabitants of Sverdlovsk still remember how objects hanging on the walls moved, and how chandeliers and lamps swung to and fro. Cracks appeared in some of the houses, and in Pervouralsk (at that time there was only a small factory settlement there, but now it is a city) the factory chimney stack fell down. There were no victims, but the phenomenon, being unusual for these places, made a great impression.

The third group covers earthquakes of the seventh, eighth and ninth grades. Scientists call these earthquakes destructive and even devastating. Indeed, they cause great damage. Tall buildings fall down, the ground sometimes cracks and human casualties are not infrequent.

In 1960 I witnessed the result of such an eighth grade earthquake in the Albanian town of Korce. During the subterranean shocks the minaret of an ancient mosque fell down, and several buildings fell to pieces. Only the fact that the strong shock

was preceded by several weak ones made it possible to avoid casualties. The population abandoned the town beforehand and stayed in a safe place until the underground shocks were over.

Earthquakes of the last group, which covers shocks of grades ten, eleven and twelve, are known as catastrophic. The Chilean tenth-to-eleventh grade earthquake belonged to this group. Another earthquake of this group was that of 1948 when the City of Ashkhabad was entirely demolished. Only three buildings of special antiseismic design remained intact. Such buildings are erected in places which are prone to destructive or catastrophic earthquakes. They are built of concrete with very rigid fastenings of special design. Their foundation must be an integral monolythic rock; it is known that structures that stand partly on rock and partly on loose soil are the first to collapse. Flexible hose is used in antiseismic buildings to connect them to the water and electricity mains, because during strong tremors when the Earth yawns open and then closes up again, ordinary rigid electric wiring is likely to tear and cause fires. These are very difficult or impossible to extinguish as the water supply system is often put out of order in such cases. The horrors of the famous Tokyo earthquake of 1923 were greatly multiplied by the fact that those who survived the shocks and the yawning cracks perished in the fire that raged for four days after the earthquake.

Scientists have long been striving to organize a warning service which could notify people of oncoming earthquakes. How this would help the inhabitants of the dangerous zones, and lessen

the tragic consequences of these catastrophes!

To do this it is necessary to understand the code of information the Earth itself sends us, and to answer three seemingly simple questions: where and when is the earthquake likely to occur and what will be its force? The first and third of these questions are not difficult to answer. Seismic stations listen in carefully to all tremors of the Earth. In the U.S.S.R. such stations have been set up in Moscow and Sverdlovsk, in Yakutia and Franz-Josef Land, in Petropavlovsk-Kamchatsky, in Ashkhabad, and in many other places. Experts mark on maps all the zones where earthquakes have ever occurred. The marks on the map also indicate the strength of the underground shocks. This makes it possible to outline the regions of predominantly catastrophic earthquakes, those where earthquakes are less destructive and regions of mild earthquakes.

We know, for instance, that catastrophic earthquakes are likely to occur in Central Asia and the adjacent territories of Iran and Iraq. Such earthquakes also threaten Mongolia and the neighbouring regions of Lake Baikal and the Trans-Baikal. Many catastrophic earthquakes take place in Eastern Asia and on the Pacific coast in general. In all these zones measures must be taken to prevent the devastating consequences of these catastrophes: antiseismic buildings are erected with antiseismic utility connections, and transport is kept in a state of readiness to evacuate the population.

It is much more difficult to answer the question of when the earthquake will occur. But when scientists learned to decode the Earth's signals

more fully, it was found that great changes take place in the magnetic field and the tilt of the Earth's surface a few hours before an earthquake. If special tiltmeters are set up in the danger zones earthquakes can be forecast several hours beforehand by watching the position of the bubble in the liquid of the instrument. Preventive measures can then be taken. By connecting the tiltmeters with an automatic signalling system warning of the coming catastrophe can be given quickly and without fail.

But how are these signals from the depths decoded?

In the Central Urals, in the vicinity of Sverdlovsk, a uniform rock, a large massive mountain consisting of rocks of uniform-type structure, was selected as the site of a seismic station. Deep down in a basement seismographs are installed at various angles, to listen in continuously to the rhythm of the Earth's life.

The recorder pointer slowly rises and falls, drawing curves of various amplitudes on a rotating drum. Suddenly a sharp peak appears on the tape, then another.... The amplitude of the curves reaches a limit value. Alarm bells trigger off in the observatory, and red lights go on. This means that in the Philippines, on the Hawaiian Islands or in Antarctica there is an earthquake, and the Earth is breaking.

The operator, who keeps careful watch over the behaviour of the seismographs, can calculate from the angle of incidence of the seismic rays where and when the earthquake occurred and its intensity. Then the information service sends in a report to a special centre where the data

received from all seismic stations are generalized and refined.

Each tremor of the Earth pierces the globe through and through. The seismic waves are reflected or refracted by the various layers of the Earth. Each refraction and each reflection gives its own signals. This information from the depths needs only to be decoded. Numerous comparisons of earthquake data have given scientists an idea of the uniform structural pattern of the bowels of our planet.

We have already seen that clearcut seismic signals come from the Moho, the discontinuity between the upper mantle and the Earth's crust. But this is not the only boundary registered by seismographs. Several zones lying concentrically inside the Earth are now distinguished by the acceleration or deceleration of seismic waves passing through them. These zones are known as geospheres.

The major zones are the Earth's crust, the mantle and the core, but individual subzones or layers are delineated quite distinctly in each of them, as in the Earth's crust.

Take, for instance, the Earth's mantle. It accounts for about 70 per cent of the entire mass of our planet. Beginning just beneath the crust, the mantle extends to a depth of almost 3,000 (more exactly, 2,900) kilometres below the surface of the Earth. In the mantle zone the velocities of seismic waves increase rapidly, and then decrease again, dividing the mantle into upper and lower parts. The upper mantle, in its turn, subdivides into several layers. The first layer, known as the ground or subcrust layer, is about

100 kilometres thick (it is sometimes observed down to a depth of 150 kilometres). The magmatists say that it contains many volcano-feeding hearths. This is where the centres, or foci, as geologists call them, of earthquakes are situated.

The subcrust layer is followed by a layer of relative repose. This lies at a depth of 150 to 200 kilometres. Recently this layer has come to be known as the Gutenberg layer in honour of the prominent geophysicist who first developed the elementary scheme of the inner structure of the Earth we are describing. Then comes a nameless layer which does not seem to be remarkable for anything in particular and lies 200 to 400 kilometres below the surface.

Then, at a depth of 400 to 800 kilometres, the velocity of the seismic waves suddenly begins to increase sharply. This part of the mantle has been named the Golitsyn layer in honour of the Russian scientist and academician who put all seismic phenomena and earthquakes on a scientific footing. Because of B. B. Golitsyn seismology became a mathematically grounded science.

The layer named after Golitsyn is distinguished by high activity. The centres of the greatest, so-called deep-focus earthquakes, are situated here. For a long time scientists could not account for the fact that the centres concentrate in this zone. Finally, the development of the modern conceptions of atomic structure gave the clue to the interpretation of the processes taking place in the Golitsyn layer. It has been established experimentally that at pressures of the order of one hundred thousand atmospheres the electrons in the outermost electron shells of atoms are forced

from their orbits and pass into lower orbits. All the experimental units in which pressures of this magnitude were attained exploded. Scientists assume that Earth tremors originating in the Golitsyn layer are related to electron shells being removed from atoms. Explosions of tremendous force often take place there, causing terrible destruction on the Earth's surface.

Next comes a zone which is almost completely quiet; it is also nameless. It can be traced at depths of 1,200 kilometres and more from the surface. Here the lower mantle of the Earth begins. The seismic waves reach an almost limit velocity of 12-12.5 kilometres per second, travelling through the entire lower mantle at about the same speed. At a depth of 2,900 kilometres there is another sharp drop in the rate of propagation of seismic waves.

Still deeper lies the Earth's core. Scientists are forever arguing about its composition. The Earth is subject to two kinds of vibrations: longitudinal and transverse. The longitudinal vibrations arise as compressions and expansions of matter along the direction of propagation of a travelling wave. The transverse vibrations are due to a sort of twisting of matter; in this case the vibrations of matter are at right angles to the direction of propagation of the wave. Longitudinal waves travel faster than transverse ones.

On passing from the Earth's mantle into its core the velocity of the longitudinal waves drops suddenly from 12.5 to 8.5 kilometres per second. The same thing happens to the transverse waves: their velocity drops from 7.5 to 5 kilometres per second.

Scientists have calculated that the surface of the Earth's core has an area of 147.7 million square kilometres. The same figure—147.6 million square kilometres—represents the total area of all the continents of our Earth. This coincidence seemed strange and gave rise to many hypotheses. Among them were those which were more amusing than profound. It would be worth telling about them in greater detail, were the history of science not so full of similar examples. It is known that in the Middle Ages thinkers considered the number seven sacred on the grounds that the human head has seven openings, that there were seven planets in the heavens and seven days in the week. This coincidence seemed full of a deep, mysterious meaning. But what came of it? It turned out that there were not seven, but nine planets. And the cabalistic mystery fell to pieces. If a lover of such comparisons happened to find, say, a butterfly with a wing area of 147.7 square millimetres, what wonderful conclusions he could draw! The coincidence between the areas of the Earth's core and dry land is most probably purely a matter of chance. And so let us leave these hypotheses alone and descend deeper into the bowels of the Earth.

Like the crust and the mantle, the core is also non-uniform. Down to a depth of five thousand kilometres from the Earth's surface very weak transverse waves can still be traced, but after this they die out altogether in the so-called inner core. Now, what is the state of the matter in the outer and inner cores? If it is already many times harder than steel in the mantle (for instance, in the lower mantle it is 3-4 times harder), then

what is it like below the mantle? But here we find a strange, so far inexplicable thing. The rocks in the Earth's core are only about twice as hard as steel.

Physicists tell us that transverse waves die out in a liquid. The transverse waves are damped in the outer core. Nor do they pierce the inner core. Then are these zones liquid? But what kind of a liquid is this, twice as hard as steel? And is it a liquid at all?

At one time it was said that the substance of the core is neither solid nor liquid, but quasi-liquid.

But recently evidence has been obtained that it is actually liquid. The geophysicist M. S. Molodensky, a Lenin Prize Winner, carried out calculations of the variations in the positions of the poles. He relates these variations to the state of the internal regions of the Earth, primarily its outer and inner cores. It follows that the poles can shift only if the substance there is in the liquid state. Molodensky's calculations are sufficiently convincing and his theory is quite logical, but it is still difficult to imagine a liquid substance twice as hard as steel. It must be a most extraordinary liquid!

But that is how the Earth's code of information, recorded by seismographs, is interpreted these days.

Key to the Gravity Code

Three properties are inherent in matter, says the ancient Hindu wisdom. The first is called "sattva". It means lightness and purity.

The second, "rajas", signifies stability, energy and motion. The third is "tamas" meaning weight, darkness and inertia.

Yes, the ancient Hindus were already aware of what weight is. Two of the eight magic forces they dedicated to the problem of weight. The sorcerer and the magician, they thought, could at will become exceedingly light or very heavy.

There is a curious story in Russian folklore about the hero Svyatogor who boasted of his strength, claiming that he could overturn heaven and Earth if he could get a grip on them.

But suddenly up rode Mikula Selyaninovich, a ploughman. He threw down his knapsack and challenged Svyatogor to pick it up. Svyatogor tried to pick it up sitting on his horse, but could not. So he dismounted and tugged with all his might, but only sank knee-deep into the ground. Another effort, and the Earth swallowed him up altogether. All the weight of the Earth was in that knapsack, says the epic, and it was beyond the strength of even the greatest hero.

Many peoples have other legends about the Earth's weight. We might mention the story of the hero Potok and Prince Marko, a Yugoslav knight. And a medieval tale of Alexander the Great tells of how he reached the Garden of Eden and there found a small stone which it was impossible to lift. Perhaps these legends, apart from their purely allegorical sense, reflected ideas of the different weights of rocks as well?

People also cherished a dream of overcoming the force of gravity. The most effective of these legends is that of Mohammed's coffin. It had no weight and hung motionless in mid-air without

falling to the ground, though it was neither supported nor suspended. The law of gravitation apparently did not exist for that coffin.

It has been known for a long time now that each latitude has its own value of acceleration due to gravity for a freely falling body. It is a minimum at the equator, and slightly greater at the poles.

These differences in the force of gravity on the surface of the Earth are due to its peculiar shape. In childhood we were taught that the Earth is a sphere. Then we were told that it resembles an ellipsoid of revolution flattened at the poles. Afterwards scientists established that the Earth resembles only itself, because no geometrical figure could be said to resemble it. And so our planet has been called a "geoid" which means something like "earth-like". A geoid is close in shape to a spheroid of revolution, but differs from it in individual convexities and concavities not provided for by geometry.

Sometimes the globe is compared to a triaxial ellipsoid. The Soviet scientists S.A. Krasovsky and A. A. Izotov proved that the Earth possesses not only a polar compression, but an equatorial compression as well. The latter, however, is very small and may be neglected in our discussion. The main compression is that at the poles, where the force of gravity and the acceleration due to it are slightly greater. The rotation of the Earth about its axis is also of some importance, increasing the centrifugal force at the equator and thus reducing the force of gravity.

The acceleration due to gravity at different latitudes can even be calculated. This calculated

field of accelerations due to gravity is usually referred to as the normal field. This is to distinguish it from possible abnormal fields, known as anomalous fields, where the general law of the gravity information code does not hold. In practice, insignificant deviations from this law can be registered at any point of the globe, and this is very important for geology, as we shall see.

The cause of many gravity anomalies is the relief of the terrain. We find anomalous fields in the zones of all major elevations of the globe: in the middle of Asia, in the Pamirs and the Himalayas, Central Asia, and in the Caucasus. Anomalous gravity fields are encountered in ocean regions too; they depend on the relief of the sea bed.

But the thing is that other gravity anomalies supplement these. Anomalous fields depend on the concentrations of various minerals and on various types of rock.

For example, scientists can detect sections of the basaltic layer that come close to the surface, not only by seismic methods, but also by determining the changes in the acceleration due to gravity. Complex instruments are employed for this purpose, the chief element of which is a pendulum. It was discovered long ago that the plane in which the plumb of a pendulum moves changes when it is brought close to high mountains or any very dense mass. Practically it was very difficult to register this change. But by using ingenious devices men have succeeded in measuring these deviations from the plumb line by the twisting of the filament suspending the pendulum. This is how the anomalous zones just mentioned

are found, giving information about the depths of the Earth and revealing the minerals concealed in those depths as well as its structural features.

Recently instruments called gravimeters have become widespread as a means of studying normal and anomalous gravity fields. Such instruments have also been sent up on Earth satellites. Does this not sound strange—space, weightlessness, and all of a sudden a gravimeter for measuring the force of gravity? But, as a matter of fact, when observing the motion of satellites certain deviations from the calculated orbit were detected. And it turned out that they were caused precisely by anomalous gravity fields. Therefore, to study the structure of the inner zones of the Earth, it is necessary to go up into outer space. From there the sedimentary, granitic and basaltic layers can readily be observed with the aid of a gravimeter. This is one of the practical applications of space investigations. It is at the same time an investigation of the Earth itself.

In about the thirties of this century the Dutch scientist Vening Meinesz succeeded in determining the anomalous fields in the oceans. He studied them by going down in a submarine. Later this work was continued by tens and hundreds of scientific expeditions. The earth below the surface of the oceans stopped being a "blank spot", and unveiled its geography and geology.

Gravimeters are being used more and more extensively for prospecting of minerals. Geophysicists take these instruments out to the areas where they are prospecting for accumulations of various metallic and nonmetallic minerals, and register

even the slightest variations in the acceleration due to gravity. This data, recorded on appropriate geophysical charts, shows the distribution of positive and negative gravity anomalies.

Oil and gas are sought, as a rule, in zones of negative gravity anomalies, as these minerals fill voids in the Earth's crust. The zones of positive anomalies are where heavy, dense accumulations occur, these being connected with concentrations of mineral ores. Geophysicists "weigh" the ground, noting where light, and where heavy rocks lie.

Interpretation of the gravity readings coming from the depths of the Earth enables us to talk about a considerable number of regularities of structure of both the surface and the deep-seated zones.

Scientists have established that the average density of the Earth as a whole is 5.52, while the average density of the Earth's crust is not more than 2.63. Therefore, if light rocks occur on the surface and in the Earth's crust, there must be heavy ones nearer the centre. A simple conclusion could be drawn: the density of each separate layer of the inner zones of the Earth could be determined by carrying out a few not very involved mathematical operations. But this simplicity was such only in appearance. Again everything depended on the fundamental standpoint adopted in estimating the state of the inner zones of the Earth. Here we once more meet with our old friends the magmatists and the neptunist-transformists.

At the turn of the century, when the magmatists almost completely dominated, geologists and geophysicists were very fond of comparing

blast furnace operations with the history of the development of the Earth from its planetary days to the moment it became covered with a solid crust.

Have you ever watched what happens in a molten mass of iron just smelted from the ore? It is a beautiful and instructive sight. On the surface of the dazzling bright molten metal there floats a thin film of slag. If you are a bit slow in pouring the metal this film becomes a dark dense and strong crust. This is what was said to resemble the outer shell of the globe, which formed when the immense mass of molten matter cooled down.

Analysis of the slag film shows it to be an accumulation of silicon and aluminium compounds. If we now have a look at the Earth's crust and its chemical composition, we find that it too contains a great deal of silicon and aluminium together with other elements. That is why the prominent scientists Suess, Wiechert and Goldschmidt suggested calling the Earth's crust "sial", this name being a combination of the first syllables of silicon and aluminium. Calculations by geologists and geophysicists revealed that below sial there must be a denser mass containing silicon and magnesium, and so this zone was called "sima" (the initial syllables of silicon and magnesium). According to these scientists the core, where the heaviest mass should lie, consisted of nickel and iron, and so this part of the Earth got the name "nife" (ferrum being the Latin for iron). That is how most scientists at the beginning of our century imagined the inner structure of the Earth.

These views were expressed most fully by Alexei Tolstoi in his novel *The Garin Death Ray*. It is known that when writing his novel Tolstoi consulted Academician Fersman on the question of the inner structure of the Earth, and Fersman sided with the magmatists.

Remember how the great writer pictured the occurrence of different rocks in the depths near the Earth's centre. Garin asserted that light rocks lay beneath the Earth's surface. Then after he passed through the Earth's crust there should be the so-called olivinic or peridotitic layer or belt consisting of ultrabasic rocks, and still deeper would be the ore shell of the Earth, which was supposed to include a layer of pure gold. It was this gold that Garin was after.

As we remember, Garin got what he had been looking for. All the layers were passed through by sinking a very, very deep shaft. Finally, after a large number of complicated situations, the workers cut into the gold layer. However, when the precious metal was raised to the surface and the world found out about it, gold lost its value.

But while agreeing about the main issue, viz., the distribution of the Earth's layers, magmatists argued endlessly among themselves as to the most accurate way of interpreting the Earth's gravity information code, as to how the density of the rocks changes as we move deeper into the planet, and whether this change is gradual or abrupt. In all these calculations both the data of the blast furnace process and the general magnetism of the Earth were taken

into account. Even today there are those who think that the Earth's magnetic field is related to its iron core. Now if we assume that the inner zones of the Earth are made up of iron masses, the calculations become very simple. The density of iron, or rather, iron-nickel masses is about 10-11, while the density of the Earth's crust is 2.63. Thus, it only remained to calculate the average density of each of the depths. It was by these density values that the silver, gold and other belts were outlined.

In 1947 a huge meteorite thundered across the sky. It was like a volley from a whole battery of large-calibre cannon. This meteorite broke up into pieces over the Sikhote-Alin taiga. Immediately a group of scientists was dispatched to find it. Over 50 tons of meteoric iron containing admixtures of nickel and other elements were collected.

Possibly, said the adherents of the magmatic hypothesis, meteorites are fragments of the core of a once existent planet. Possibly, rock meteorites are the remains of the crust, and iron-nickel ones of the core, of the planet that was once located in the region of the present-day asteroid belt between Mars and Jupiter. And if this is so, then it was one of the insignificant fragments of this planet, calculated to weigh about 50 thousand tons that fell in the Sikhote-Alin taiga. The greater part of it, about 99.9 per cent, burned up on passing through the dense layers of the atmosphere, while 50 tons, or one thousandth of it, remained. But these unburned fragments were metallic.

The magmatists' assumptions turned out to be

true. Those who had taken into account the abrupt changes in the rate of propagation of seismic waves inside the Earth, said that the densities inside the Earth could not be imagined to change gradually from light to heavy masses. In their opinion these density transitions were abrupt in nature.

The magmatists' antagonists, the transformists, argued that the inside of the Earth and its history could not be likened to what takes place in a blast furnace. A number of scientists who grouped themselves around Academician Otto Yulyevich Schmidt attempted to decipher the gravity information code from a different approach. One of the scientists of this group, Professor Y. N. Lyustikh held that the Earth, in agreement with Schmidt's theory, had never been in a molten state. Concentrated from separate fragments of meteoritic matter, it must be pictured as a heterogeneous mass. O. Y. Schmidt's adherents denied the hypothesis of the planetary origin of meteorites. They considered that meteorites are much older than planets, and that they are the primary parts of the primordial nebula from which all the planets and their satellites originated, including the Earth and the Moon.

And so, according to Lyustikh, the Earth may contain accumulations of former meteorites, regions of light and heavy masses. Each rock possesses a definite viscosity. Owing to this the lighter substances may rise to the top while the heavier sink. Lyustikh calculated that a body about three kilometres in diameter can sink (if it is heavy) or rise (if it is light) at a

rate of about 500 kilometres in 1,000 million years. Bodies of smaller size move at a slower rate. During the same 1,000 million years a body with a diameter of one kilometre could sink or rise only 50 kilometres. During this vertical movement of rock bodies inside the Earth so much energy is liberated that melts are likely to appear in some zones. The amount of energy is large enough to account for all the processes of crumpling of rocks.

Another scientist of this group, G. D. Panasenko, puts forward still more complicated ideas on the inner state of the Earth. He says that we must take into account the laws of physics and chemistry related to the internal structure of the atom.

If we take, for instance, an atom of platinum and imagine it enlarged to the size of a skyscraper 32 storeys high, the nucleus of this atom, which contains almost all its mass, would occupy not more than a cubic centimetre.

If a certain number of electronic shells are torn off, atoms can be brought closer together. The substance, while retaining its chemical composition, would become slightly denser, and heavier. And maybe it is not so very necessary, says Panasenko, to imagine the Earth stratified with respect to chemical composition. The latter may be uniform both in the surface and in the deep-seated zones.

But under the influence of the immense pressures existing inside the Earth changes may occur in the structure of the atoms. Calculation shows that at the centre of the Earth the pressure must be as high as three million

atmospheres, and at the boundary between the core and the mantle it equals one and a half million atmospheres. Such a tremendous pressure will, of course, cause a rearrangement in the atoms. Their state will be nothing like what we know on the surface. Changes will occur in their inner structure and in the density of their spatial arrangement. Rocks with the same chemical composition will have entirely different densities at different depths. These density variations may be abrupt.

It is known that atoms bereft of their outer electron shells acquire metallic properties. Why, for instance, must we think that the inside of the Earth necessarily contains iron? It may be some other substance which has acquired metallic properties because of the change in its atoms.

That is how scientists these days attempt to interpret these two figures, the density of the Earth and of its surface.

Just recently it was suggested that among the elementary particles of the atom there may be a graviton, i.e., an elementary particle, a bearer of the force of gravity (whence the name). In the course of the lifetime of the elementary particles the graviton may yield a positron and an electron, and it may be decomposed into other elementary particles. If the graviton hypothesis is right, we acquire new perspectives, and new possibilities of proving that the weight of a substance varies with depth. Perhaps we are not far from solving the problem of overcoming gravity?

The key to the Earth's gravity code has not yet been worked out in full. Many problems of

both scientific and national-economic value depend on the solution of this task. Probably the time is not far off when a uniform theory of the Earth's structure will be worked out, and this will open out new possibilities, in particular, for prospecting and mining.

Heat and Cold

In his very interesting book *The Universe, Life and Reason* Professor I. S. Shklovsky puts the question: "Is there life on Earth? Of course, this is from the standpoint of intelligent creatures that might be inhabiting other planets, Mars in particular.

The first impression of the Earth would not be very consoling. When determining its temperature our celestial neighbours would discover some remarkable things. They would find that the surface of the atmosphere has a very high temperature and, of course, would draw the conclusion that there could be no life on Earth at that temperature.

At the same time they would notice a strange paradox, namely, that in spite of this high temperature, the Earth is not luminous. If they were to study the temperature of the bottom layers of the atmosphere with radio telescopes, they would be still more astonished. Here the temperature is far below 100 degrees, and sometimes drops sharply below zero. It would seem that life is possible under such conditions.

Such are the riddles our planet puts to those who study it from outside. However, the riddles

it sets us are no less strange and surprising.

Early in 1963 astronomers got together at the Gorky Kremlin to discuss some of the scientific data obtained in recent years. Special attention was drawn to the work of a group of Gorky scientists who had set up an artificial moon almost 5 metres in diameter on Peak Ai-Petri in the Crimea. The moon model was made to check the data obtained in investigating the surface of the real Moon.

Working under the leadership of Prof. V. Troitsky, D. Sc. (Physics and Mathematics), the scientists established a number of curious facts.

First of all, they determined the kind of rocks that constitute the lunar surface. It was found that with respect to heat conductivity they greatly resemble our neutral, basic and acidic rocks. These are gabbros, diorites and granites.

It appeared that the temperature of the Moon's surface is subject to sharp fluctuations due to heating by solar rays. But at a comparatively small depth below the surface the temperature is already more or less constant. Further down it rises and at a depth of 50 or 60 kilometres it reaches 1,000 degrees.

They succeeded in plotting the temperature curve of the Moon. It was found to rise continuously, and the scientists came to the conclusion that here was a complete analogy with what we observe on Earth.

Or do we? Can scientists say that they are able to plot the temperature curve of the Earth? This question can be answered only with a certain degree of probability. And the question

should be divided into two unequal parts, each to be answered separately. The temperatures of the Earth's atmosphere differ greatly from those of its inner parts.

We can plot the temperature curves for the atmosphere quite accurately. Indeed, the observations that could be made from the surface of Mars would be confirmed by the investigations made on Earth in recent years. At high altitudes the temperature reaches very great values, and becomes lower on approaching the Earth's surface. Here we should detect two temperature minima and two maxima, which in many respects determine the type and nature of the temperature curves of the "sky".

The coldest zones are situated at heights of 50-70 and 10-30 kilometres above the Earth's surface; the heat maxima are at 100-150 and 40-50 kilometres. In the cold zones the temperature drops to minus 70-75 degrees, while in the hot zones it rises to 100 degrees and more. In the upper maximum it reaches several thousand degrees. We have come to know all this by employing the most up-to-date methods of observation, including geophysical rockets and artificial Earth satellites.

But if the Martians decided to determine the temperature of the underlying layers of our planet, that of the mantle and the core in particular, they would come up against insurmountable difficulties. Unfortunately, we inhabitants of the Earth are not much better off in this respect. There are many assumptions and hypotheses (the Martians could have suggested them just as well. Remember, for instance, our

controversy about the temperature of Venus!). But as to exact facts, they are almost completely absent.

Back in the nineteenth century it was observed that the temperature increases gradually with depth. In small mines and not very deep holes the temperature rises an average of one degree per 33 metres of depth. These figures were included in textbooks the world over, and their authority became indisputable. But when deep mine workings were started it became clear that these average data gave no grounds for drawing conclusions as to the temperature conditions even in the surface zone of the Earth! The temperatures in different parts of the continents were found to differ sharply. In some cases it was far above the average, and in others far below. And sometimes the temperature first rose, then dropped sharply. Thus, it appears that each district of the Earth's surface has its own temperature conditions.

For example, on the Kola Peninsula the temperature rises an average of one degree per 150-160 metres of depth. Approximately the same increase is observed in a large number of oil wells in the Volga district. These changes, moreover, take place by steps, not smoothly. In many cases they even occur in sharp jumps, depending on the circulating subsoil waters.

There is a small town in the Southern Urals, called Yangan-Tau, where the temperature rises abruptly at first until it reaches plus 300 degrees at a depth of 300 metres. Then, at greater depths, it falls off again. Here we have a sharp temperature anomaly. Possibly it is related to proc-

esses of carbon oxidation or radioactive decay. It has been noticed, for instance, that the gas issuing from the zone of maximum temperature is slightly radioactive.

Many other regions with anomalous temperatures have been detected on the globe. And these anomalies defy all regularities.

But if we were to admit an increase of temperature with depth of 1 degree per 33 metres to be the general law, we would obtain for the zone of the Earth's core the frightening figure of not less than 200 thousand degrees! If such a temperature actually existed at the centre of the Earth, our planet would long ago have blown up and become a gas cloud. For this reason, when considering questions of the temperature conditions in the inside zones of the Earth, scientists arbitrarily reduce this figure.

For example, Guttenberg, who studied this question at the end of the last century, held that the temperature below the Earth's crust is more or less constant and does not exceed four or five thousand degrees. Other scientists state that the temperature of the Earth increases regularly with depth, but name ten thousand degrees as the maximum temperature in the core.

Only Academician Vernadsky as far back as 1934 put forward the idea that the temperature may drop with depth. His assertion met with sharp criticism from many of the scientists at the XVII International Geological Congress, mentioned at the beginning of this book. This was the force of tradition, the habit of a "convenient hypothesis", in action.

Vernadsky's views found great support in

O. Y. Schmidt's theory. And when radioactive phenomena were taken into account, scientists had proof in their hands of the complexity of the thermal life of the Earth. It was assumed that if radium, thorium and uranium were more or less uniformly distributed throughout the Earth, it must be becoming hotter. The accumulation of heat due to the decay of radioactive substances must be so great that the Earth should long ago have gone through the stage of complete fusion.

Not so long ago Y. A. Lyubimova, a Candidate of Science (Physics and Mathematics) at the Institute of Physics of the Earth of the Academy of Sciences of the U.S.S.R., calculated the heat balance of the Earth. Proceeding from the average figures for the distribution of radioactive substances in the Earth's crust, Y. A. Lyubimova assumed that the distribution in the depths must be the same, and this should result in the formation of a hot mass at the core of the once cold planet. She calculated how long it would take for the Earth to melt altogether, determined the nature of the deep-seated processes and how this heating would affect the course of earthquakes, and the crumpling of the surface zone of the Earth. In other words, these calculations show that the Earth is at present getting hotter.

But it has not as yet been proved that radioactive substances are distributed evenly throughout all the zones of the Earth. For this reason a considerable number of scientists, especially those who accept the magmatists' point of view, believe that the Earth has already gone through

the stage of melting and is now cooling down again, and that mountain ranges arose as a result of the volume of the planet decreasing. This process is compared with what happens to the skin of a baked apple which wrinkles up as it dries.

Another interesting standpoint is that of the adherents of the hypothesis of convection currents in the Earth's mantle. These research workers consider that the surface of the Earth is cooling down, while currents of heat come out from the depths of the planet and thus maintain the heat balance.

But what if we accept Academician Vernadsky's point of view and imagine that the temperature of the Earth did not rise in the past? Then it may be assumed that there are sections with negative temperatures in the depths, in the zones situated far away from the Earth's surface. By analogy with the Earth's atmosphere and its outer shell, and making allowance for the peculiarities of the medium and its physical conditions, it may be supposed that the depths of the Earth also feature certain temperature maxima and minima. Perhaps in some places the temperature is close to absolute zero. Is not this the solution to the riddle of seismic signals which seem to indicate that there is a liquid mass inside the Earth?

It is known that at temperatures near minus 273 degrees superfluidity phenomena begin to occur; rocks abruptly acquire new properties quite foreign to them at ordinary temperatures. Does this not account for the peculiarities of the substance of the depths?

Such are the questions that arise when we begin to study the temperature distribution in the bowels of our planet. And so two opinions continue to clash. One, that the temperatures inside the planet are high and very high; the other, that its internal zones are cold. Which of them is right? Science cannot answer this question as yet.

You Will Not Find This in Any Textbook

There is a very beautiful Bashkirian legend which tells how the nomads fended off the attacks of the Mongol Tatars. A battle was raging at Mount Magnitnaya.* The surviving handful of defenders fell back close to the hill, hard pressed by the invading hordes who kept advancing, shooting clouds of arrows. But what was this? Before the eyes of the astonished archers their arrows flew wide and missed their marks. They were attracted by the magnetic hill defended by the brave warriors. "Sorcery!" decided the frightened Mongol Tatars, and turned tail.

Thus are the properties of the magnet recorded in folklore. We know, of course, that neither the magnetite of Mount Magnitnaya, nor that of any other deposit possesses such a force. Once they decided at the museum of the Sverdlovsk Mining Institute to put on display a piece of magnetite that would attract iron

* Magnitnaya is the Russian for "magnetic".— *Tr.*

articles. But of several hundred specimens examined only one was found that could attract iron needles and small nails fairly well. Such a magnet could not, of course, attract an arrow.

If we take an ordinary magnet of the kind used for simple experiments at school, we can see how it attracts a compass needle, making it rotate. And when we try to account for the magnetic force of the Earth, we involuntarily reason by analogy, imagining an immense iron core concealed inside the Earth.

But is there actually such a core in the Earth? If we accept the hypothesis of the magmatists and compare one of the stages in the development of the Earth with the cooling of pig iron, the analogy with the magnetic iron core comes up of its own accord. But what about the Curie point? That is, the temperature of 760 degrees Celsius, at which the magnetic properties of iron disappear. Then the temperature inside the Earth must be below 760 degrees. But this conclusion would hardly suit the magmatists. It contradicts their theory of the molten state of the Earth's core.

In order to reconcile the assumption of the existence of an iron core in the Earth with the idea of the high temperature of its core, scientists sometimes resort to mathematical calculations. One such calculation showed that the Curie point is dependent on the pressure, and that at a pressure of three million atmospheres it should shift to 4,240 degrees.

Magnetic information!... It has to be ably interpreted, and the information on how the magnetic needle behaves is very diverse.

About 300 years ago the London Royal Society decided to carry out systematic observations of the behaviour of the magnetic compass needle. They began by studying its inclination. It is known that it points at the magnetic, not the geographic, pole. There is always a certain angle between the direction shown by the compass needle and that of the geographical meridian. This angle is known as the inclination. It can be determined for each point of the globe. If we then draw lines through points with equal inclinations, we get the magnetic meridians of the globe.

Knowledge of the inclination is very important for sea-farers and flyers. Not so long ago the magnètic needle was the chief means of taking bearings when plotting the course of a ship. The observations made over three hundred years by the London Royal Society are of great interest today, also. From the inclination and other data we can determine the Earth's so-called normal magnetic field, which has its own peculiar regularities. It appears that it does not remain constant, but keeps shifting all the time. At present such observations are carried out by all the major geophysical observatories of the world. In order to define the normal magnetic field fully, observatories record not only the inclination, but the magnetic dip as well. The compass needle is parallel to the horizon only in the zones close to the Equator, but at the magnetic poles it ought to stand practically upright. In the middle latitudes the compass needle tilts at various angles to the horizon. The lines joining the points of the

globe with equal dip values approximately correspond to the latitudes.

It is said that the third component of the magnetic field is the force of attraction between the needle and the pole. And men have learned to measure and express it as definite values. Near the poles this force is much greater than at the Equator.

If we draw an imaginary line through the globe connecting the magnetic poles, a line known as the magnetic axis, it will be seen that it does not run through the Earth's centre but misses it by a distance of 1,200 kilometres. Thus, if the magnetic field of the Earth is due to an iron core, the magnetic source must be situated eccentrically in the planet, i.e., closer to a certain part of the Earth's surface.

But here again we come to a contradiction with the facts. When considering the structure of the Earth according to seismic data, we saw that the inside of the planet consists of concentric geospheres, and that there are no spheres eccentric to the Earth's surface. How are we to reconcile this contradiction between seismic and magnetic information? There can be only one conclusion: there is no iron core inside the Earth!

We know that in a number of places the normal magnetic field of the Earth is disturbed. Sharp anomalies are observed in these zones, so that sometimes the compass needle points in any direction but that of the pole. One of the greatest magnetic anomalies of this kind in the Soviet Union is that of the Kursk, Belgorod and adjacent regions, called the Kursk Magnetic Anomaly.

This anomaly was studied before the October Revolution by Leist, a professor at Moscow University. He mapped the areas of strong and relatively weak anomalous zones. Leist attributed the anomaly to the presence of large accumulations of iron inside the Earth.

During the Revolution Leist's material was taken out of the country, and during the very first years of Soviet power the Germans attempted to sell them back to the Soviet Government. V. I. Lenin, who took up this question personally, refused to buy Leist's material and entrusted the geologist Gubkin with the leadership of a new expedition for investigating the Kursk Magnetic Anomaly. This work continued for quite a long time and was finished only after the Second World War. Areas were discovered where the iron ore occurs close to the surface, and as a result the Belgorod and a number of other pits are now supplying iron and steel plants of the Central U.S.S.R. with large quantities of high-grade magnetic iron ore.

Even a modest estimate shows that the Kursk Magnetic Anomaly accounts for more than half the world's reserves of iron ore.

Such major magnetic anomalies have been observed in a number of other places as well. For instance, in the region of the Arctic Ocean there is a magnetic anomaly that stretches along the submarine Lomonosov range. There is a very strong magnetic anomaly in the South Atlantic Ocean. There are many in other parts of the globe too. Most of these anomalies have been investigated and are marked on the map. Geologists have studied many of them, and the

magnetic data have been confirmed in a number of cases by drilling.

It was found that fairly strong magnetic information comes to us from different sections situated comparatively close to the Earth's surface. These sections are related to the structural peculiarities of the Earth's crust. When the magnetic information code was deciphered, it was found, and later confirmed by drilling, that the surface of the granitic layer underlying the sediments in the European part of the U.S.S.R. exhibits sometimes bulges, and sometimes big, deep depressions. This gave an idea of the relief of the foundation of the European part of the U.S.S.R.

In some places the foundation comes up close to the surface. This happens in Karelia on the Kola Peninsula, in the Ukraine and in the vicinity of Voronezh. At other places it lies at very great depths. Such is the case near Sarapul, in the adjacent parts of the Tatar and Bashkirian A.S.S.R. and in the Perm Region, within the so-called Sarapul Depression, where the foundation is 10-12 kilometres below the Earth's surface.

So far geologists do not know what caused this gigantic "kettle" in the European part of the Soviet Union. Doubtless, one of the proposed super-deep holes will be drilled in the Sarapul kettle, but at present we can only suggest hypotheses as to the causes of this enormous depression.

The code of magnetic information is not confined to the distribution of the Earth's normal and anomalous magnetic fields. We

receive much more complex magnetic information which testifies to the fact that the Earth's magnetic field does not remain constant, but keeps changing all the time. Each second the magnetic field is different from what it was before.

Very many types of changes, known as variations, of the Earth's magnetic field are distinguished. Besides short-lived periodic perturbances, changes have been detected that depend on the time of day (daily variations) and on the season of the year (annual variations). There are still more complex ones—centennial and even geological variations of the Earth's magnetic field.

When studies were made of the shorter variations, the minute, daily and annual ones, it was observed that their distribution bears a distinct relation to what is happening on the Sun.

On February 23, 1956 at 8 a.m. Central European time, an explosion of extraordinary force occurred on the Sun. Its power was said to equal the explosion of a million hydrogen bombs. A short time later, a magnetic storm began on Earth. Radio communications were interrupted, and in some places telephone lines went out of order. Even the speed of rotation of the Earth about its axis changed. The Earth slowed down its motion for one hundred thousandth of a second, which is a great deal for such an extremely precise mechanism as a moving celestial body.

Strong earthquakes also affect the magnetic field of the Earth, especially deep-focus earth-

quakes with their disturbance zones located in the Golitsyn layer at a depth of about 800 kilometres from the surface.

There are other regularities that have been noticed by magnetic observatories. Long-term observations have shown that the normal magnetic field of the Earth is subject to regular secular fluctuations. Observation data are entered annually on a special chart and their comparison makes it possible to trace the regularities of the secular change of the normal magnetic field.

But can an ancient magnetic meridian be "seen", can an ancient normal magnetic field be revealed? It appears that they can. There are methods of studying what is known as the residual magnetism characteristic of ancient geological epochs. To put it simply, any particle situated in a yielding medium is an independent magnet whose poles are aligned with the magnetic pole of its particular epoch. When the medium hardens, the ancient meridians become petrified in it. A fossil meridian!

It was mentioned above that the Curie point in a molten mass is 760 degrees. Imagine a flow of viscous semi-liquid lava issuing from the funnel of a volcano. As long as the temperature of the lava is above 760 degrees, the Earth's magnetic field will have no effect on it. But as soon as this boundary is passed, separate tiny magnets will begin to appear, and they will immediately line up with the magnetic meridians. Then the lava begins to solidify and as soon as it freezes the direction of the magnetic particles in it also freezes. That is how fossil meridians of past geological epochs appear in lava.

The same occurs in viscous sea ooze, in which certain constituent particles also orient themselves along ancient magnetic fields. When this ooze hardens the ancient meridians in it also harden.

Geologists learned to draw the outlines of these ancient meridians, and when the data for all continents was generalized it was found that the magnetic poles had been situated in different parts of the Earth during different geological epochs!

Here is how the North Pole "travelled". Fifteen hundred million years ago it was in the region of the Canadian lakes; then it began to shift latitudinally to the west and a thousand million years later it was in the centre of the Pacific Ocean, in the zone of the Hawaiian Islands. It took it another 200 million years to cover the distance from the Hawaiian Islands to what is now the coast of the Far East. Then it turned sharply north and moved along the north coast of Asia. A hundred million years ago the pole was situated in the zone of Bering Strait, and then it continued its "journey" until it finally reached its present-day location.

A curious detail came to light when studying the movements of the pole. The lines of the ancient meridians of different continents did not converge to the same point. This gave the impression that several magnetic poles existed in the same geological epoch, which is quite absurd, of course.

It occurred to one of the scientists to restore the outlines of the continents as Wegener had once pictured them. The result was astounding!

If, following Wegener's hypothesis, we merge all the continents into one, the magnetic meridians of each epoch converge to one point. And now palaeomagnetologists, when studying the position of ancient meridians, introduce the so-called Wegener correction in their measurements. The old hypothesis unexpectedly came to life again, supported by geophysicists and magnetologists. And heated discussions started anew.

For some time the magmatists were triumphant. They had, it seemed, obtained indisputable evidence of the existence of a molten mass underneath the Earth's crust, on which the continents moved, or floated. The magmatists' adversaries objected that it was only the magnetic poles that had moved while the continents had remained stationary; the non-coincidence of the magnetic meridians was due only to the geological course of the variation of the Earth's normal magnetic field.

And so the riddle remains unsolved. Its solution is a thing of the future. A wealth of coded magnetic information is waiting to be deciphered.

New data were obtained in recent years when artificial satellites began to be launched in the U.S.S.R. and then in the U.S.A., when spaceships began to take off from the Earth to explore outer space, and when we began to study and compare the magnetic fields of the Earth, the Moon, Venus and Mars. Today it is quite obvious that our planet has the greatest magnetic field. It extends tens of thousands of kilometres above the Earth's surface.

Now scientists have outlined what is known as the magnetic sphere of the Earth, pictured as very complex lines of magnetic force encompassing the globe.

The Moon was found to have no magnetic field, at least, no magnetic field that can be recorded by the equipment installed in spaceships. The American spaceship "Mariner-2" which flew past Venus in 1962 detected no magnetic field on this neighbour of ours either. This was a very important discovery. Previously, scientists could say that the Moon has no magnetic field because its mass is too small for a magnetic field to form. But the mass of Venus is close to that of the Earth. Then why should our planet have a magnetic field while Venus has none?

It is not simply a question of mass!

Thus, the magnetic information received from outer space has again set before us a riddle which we are as yet unable to solve.

A detailed study of the magnetic sphere of the Earth has shown it to contain certain deviations connected with major magnetic anomalies. Lines which could be represented as "offshoots" run from the magnetic zones under the Earth's surface to these major magnetic anomalies. One of the largest "offshoots" has been detected in the southern part of the Atlantic Ocean. It runs to the large magnetic anomaly situated there. What is the cause of these "offshoots", and how are they to be accounted for? This magnetic information was obtained just recently and still awaits explanation.

Gradually the code of magnetic information gives us an insight into the reasons for the origin of the Earth's magnetic field. We know that there are several sources of forces affecting the magnetic field. The strongest of them is actually inside the Earth. What it is, we shall see a little later.

Another source of the magnetic field, which affects the distribution of the magnetic anomalies, is in the Earth's crust or in the upper mantle of the Earth. It is related to accumulations of rocks with various magnetic properties, very strong or very weak. Their positions affect the normal magnetic field of the Earth. Besides this, there are magnetic field sources outside the Earth, in the magnetic sphere of the Earth and, finally, 150 million kilometres away from our planet, on the Sun.

Thus, the Earth's magnetic field is not set up by just a single "iron core", but by a whole aggregate of very complex phenomena of both terrestrial and cosmic origin.

Stray Currents

In the 30's an expedition led by Eng. Mironov was working in the north. Their task was to find out whether there were any stray electric currents in the Barents Sea. The expedition was equipped with very accurate apparatus, instruments that could register thousandths of an ampere and thousandths of a volt. But when the electrodes were let down into the sea, the entire unit suddenly stopped working as if all the instruments had burnt out.

The expedition returned to fetch new apparatus. During the next experiment it was established that sometimes the stray currents in the seas run as high as several amperes, and the voltages reach tens and even hundreds of volts!

Gradually knowledge was accumulated about the stray currents that permeate not only water, but the ground as well. A definite relationship was revealed between the life of the Sun and the distribution of stray currents in the Earth. True, the passage of these currents is affected by various other phenomena, related to the distribution inside the Earth's crust of rocks that are relatively good or relatively poor conductors. The resistivity rises sharply where the strata are relatively dry and falls where the rocks are washed by subsoil waters, especially if the water contains chemical compounds.

These observations gave rise to an interesting branch of geophysics, known as electric prospecting, by means of which the conditions of occurrence of individual minerals can be established, and the arrangement of various rocks under the ground can be traced. Of course, not only natural stray currents are used in electric prospecting. Either direct or alternating current is passed through the rocks. Observation of the behaviour of the electric current in the ground gives information about the distribution of various rocks in the upper parts of the Earth's crust.

Unfortunately, the modern apparatus by means of which all these investigations are carried out is not sufficiently accurate, so that at a certain distance below the surface the

readings on the instruments are no longer satisfactory. Scientists are now working to raise the sensitivity of electric prospecting, and in connection with this, to increase the depth at which the propagation of electric currents of various intensities permeating the Earth can be studied.

For example, we do not yet know how stray currents are propagated in the zones beneath the Earth's crust. That these currents permeate the Earth in all directions is beyond doubt. But how does electric current circulate in the mantle or in the core of the Earth? And here, too, attempts to explain these processes have resulted in a clash between two opposite theories.

If, like Vernadsky and Schmidt, we assume that the temperature at a great depth is negative, close to absolute zero, we must take into account the phenomenon of superconductivity which arises in rocks at such temperatures. A current generated in these rocks will circulate through them indefinitely in the same direction, creating a giant solenoid.

The rapid rotation of the Earth about its axis in the magnetic field of the Sun must excite a huge current. Perhaps this is what causes the Earth's magnetic field. It is a fact that our celestial neighbours the Moon and Venus possess no magnetic field, and they both rotate very slowly about their axes. This assumption makes us deny the idea of the iron core of the Earth. The solenoid notion also gives grounds for the eccentricity of the Earth's magnetic nucleus, established by the magnetic signals coming from the depths of our planet. If there really

exists such a "dynamo" under the Earth's surface, it can change its contours depending on the circumstances, and this would cause a change in the Earth's normal magnetic field.

Perhaps not only the inclination, but also the dip of the compass needle and a number of other phenomena are related to this terrestrial "dynamo". And if we assume that there are several solenoids beneath the Earth's surface (which is quite likely because there may be isolated zones in the low temperature region), then some of the major magnetic anomalies of our planet may be attributed to the circulation of electric current rather than to accumulations of ferric masses. Otherwise it is difficult to understand why the centres of such anomalies shift during the secular life of the Earth.

It goes without saying that these are not more than conjectures, but the conception of an iron core in the Earth is also a conjecture based on the magmatic theory, which asserts that temperatures of thousands of degrees predominate in the inner zones of our planet.

The assumption of the Earth "dynamo", on the other hand, agrees well with the idea of a liquid core, which is most probably also due to the superfluidity of rocks at very low temperatures. Is it not here that we ought to seek the answer to the question of what the inner zones of our planet contain? Is it not here that we ought to seek new sources of energy? If we succeed in harnessing the electric currents of the Earth, this will present inexhaustible possibilities to man in his domination over nature.

Halt! Radioactivity!

All the prospectors found when they developed the film taken in the 1930's during a routine aerial survey in the district of Great Bear Lake, Canada, was that some areas near what is now the settlement of Eldorado, Labin Point, were overgrown with a great deal of milk vetch, a member of the pea family.

At that time no one attached any significance to this; it was only much later that geologists established that regions where milk vetch grows coincide, as a rule, with deposits of uranium ores.

But in those days uranium deposits were of no commercial value. All natural uranium compounds were studied for purely mineralogical purposes. And only when uranium became a most important raw material for the production of atomic weapons and for nuclear power development did men begin to explore its deposits at a feverish rate.

It was then that the old films were remembered. It became known that milk vetch is a sign of an accumulation of uranium and radium ore somewhere beneath it. It was established that a number of other plants were also indicators of zones where uranium and radium were likely to occur.

Owing to the strong radiation emitted by these elements many of the plants growing above deposits of a radioactive ore are distorted from their usual shape and give a number of freak mutations which may be manifested in changes in the colour of the flowers, stems and

leaves. Some plants have unusual shapes, and these freaks help geologists to find very valuable and important deposits.

There are other plants that grow only in places where there is no uranium ore. This is also very important. Such regions are crossed out on the map and no prospecting work is done there.

But plants are not the only indicators of radioactive ores. In many cases the rocks themselves, if studied carefully, can tell where uranium or radium is concentrated. It may be said that there is a kind of kinship between the elements of the radioactive series and certain minerals. On the other hand, uranium and radium are quite intolerant to the presence of certain other minerals.

Several years ago some petrified trees were discovered in the Colorado mine in the district of the San Miguel River deposit. One of the trunks was about 30 metres long and more than a metre thick. Another, a little less than a metre in diameter, had a length of 20 metres. Over a hundred tons of uranium ore was obtained from these trunks! From this amount of ore some six tons of uranium oxide, and about two grams of radium and a number of other elements were extracted.

This connection between uranium and radium, on the one hand, and fossil plants, on the other, has been detected all over the globe. Uranium and radium are "fond" of all remains of organic life. They are often encountered not only in petrified trunks, leaves or plant stems, but also wherever phosphoric minerals have

settled out in large quantities as a result of the accumulation of various animal remains. Uranium and radium are known to accumulate in phosphorites, those peaceful minerals from which the superphosphates used as fertilizers are made.

Uranium and radium also "like" various acid and neutral rocks, primarily those that froze in volcanic hearths. Radioactive ores are especially often found in combination with deposits of iron, titanium, and native elements, born of acid and neutral rocks.

Knowing these "weaknesses" of uranium and radium for certain elements and their minerals, prospectors search for radioactive metals where these satellite minerals occur.

At the same time, uranium and radium "abhor" sulphur. Wherever sulphur, and especially sulphide minerals occur, there is no point in looking for uranium and radium. Such zones are "taboo" to them, and therefore, you will never find prospectors for radioactive elements in places where there are accumulations of sulphide ores.

There are some other signs which indicate radioactive elements. Many minerals betray them by a specific colouring or a specific habit. Ordinarily grey, light grey, white or yellowish feldspars found everywhere in all kinds of rocks (they are even called rockforming minerals) acquire a red colour wherever there are accumulations of uranium or radium. They shout out, as it were, to the prospector: "Stop! See, I am red, and that means radioactivity. Halt! There's uranium and radium here!" And only a very

inexperienced prospector will leave this warning unnoticed.

Many more minerals and rocks could be mentioned that indicate the presence of uranium or radium in rocks. Various carbonates, limestones and dolomites also become pink-coloured, and even red or bright red where the Earth conceals accumulations of uranium and radium minerals.

It was found that radioactive minerals are very "fond" of rocks whose age runs into hundreds and thousands of millions of years. In numerous African deposits, especially in the Congo, as well as in Canada, the U.S.A. and many other areas, scientists have made detailed studies of the zones of occurrence of ancient and very ancient rocks, and have almost invariably found accumulations of uranium and radium ores.

Such minerals as quartz usually acquire a smoky or lilac colour while under other conditions they are colourless, black, or white.

There is a mineral called fluorite, which consists of calcium fluoride. Its crystals may be green, yellow, or lilac, but when fluorite occurs together with radioactive minerals it becomes violet to black or dense black. It also signals: "Stop, look around, explore!" And the attentive prospector will always find uranium minerals here.

In the surface zones uranium minerals are usually coloured various shades of bright yellow or orange, from deep to pale hues.

This change in colour due to bombardment by radioactive radiations is now utilized in industry.

Once, a long time ago, as far back as the last century or the one before last, miners in the Urals knew how to change the colour of stones, but they used primitive methods to do it. They would take, say, a piece of black rock crystal—morion—and would roll it in dough. Then they would set the dough in the oven and when the bread was baked, would take out from it a reborn and renewed stone. It was now golden yellow. This stone was famous among jewellers for its beauty.

These days such changes in colour can be effected in an atomic reactor, and the colour imparted to the minerals in this case is stable. Jewellers often make use of this method to change the colour of diamond to green, bright gold or brown. Such diamonds are highly valued.

But it would be wrong to think that geologists study only these radioactive signals from the depths. Modern equipment makes it possible to record primarily the ionization of the air, which arises as a result of active bombardment of the surrounding space with alpha-, beta-, and gamma-rays. The air becomes a conductor of electricity, and conventional electroscopes, transformed now into electrometers, i.e., counters of radioactivity, register the areas where there are zones of ionized air. These radioactivity counters are made in various shapes and are based on various principles: some pick up alpha-, or beta-, or gamma-rays; others react only to neutron radiation, etc. These counters can be employed for areal surveying by setting them up on a lorry. Radiometers are taken up into the air on aeroplanes

where they are used for aerial radiometric measurements. By means of aerial radio methods zones where the air is strongly ionized can be quickly detected. This reveals large accumulations of radioactive minerals. A detailed survey is subsequently carried out in such areas, first with various counters, and then by other prospecting methods.

Sometimes explorers come across greatly depressed radioactivity. For a long time the reason for this was unknown, but it was then established that zones of depressed radioactivity arise above oil fields. There is still much to be cleared up as regards the theory of this process, but the fact itself is used by oil prospectors when searching for oil reservoirs.

Scientists have calculated that it is the radioactive elements that in many cases account for the immense flow of heat coming from the bowels of the Earth. One gram of radium liberates 200 calories per hour during radiation. This is an enormous figure, especially if we take into account the scale on which the radiation occurs. The other radioactive elements, uranium and thorium, give somewhat less heat, but the total quantity they liberate is also large.

Japanese volcanologists have succeeded in establishing that the gases given off during volcanic eruptions contain large amounts of radioactive decay products. It is not impossible that some magmatic hearths are caused by the evolution of heat at points where there are high concentrations of radium, uranium, and thorium. True, some geologists deny this relation, but there are facts that are difficult to refute.

And how are radium, uranium and thorium distributed in the depths of the Earth? Some research workers state that the quantity of radioactive elements under the Earth's crust is smaller than in the crust. Others claim that the quantity is the same in both zones.

The only way to find out who is right is by drilling. When we get rock specimens from various parts of the Earth's mantle the answer will be sufficiently clear.

It is known that a large quantity of radioactive elements is contained in the zones of major faults in the Earth's crust. For example, the Canadian deposits in the district of Great Bear Lake are confined to such faults. Some research workers say that the connection between the radioactive elements and faults is evidence of the fact that the Earth's mantle contains large amounts of different radioactive elements; uranium, radium, thorium. Perhaps there are even more under the Earth's crust.

The radioactive signals coming from the depths of the Earth have not as yet been fully deciphered. We are still at the stage of hypotheses, but already the radioactive information received from the bowels of the Earth supplements the data on which we base our studies of the inner structure of the planet.

One of the investigators of the mysterious world of elementary particles, Lenin Prize Winner and Corresponding Member of the Academy of Sciences of the U.S.S.R. Bruno Pontechorvo tells about the wonderful properties of a particle he discovered, called the neutrino: "Imagine an iron plate a thousand million

times thicker than the distance from the Earth to the Sun. Well, the neutrino would not even notice this plate in its path; it would fly through it as if it were not iron, but an absolute vacuum."

This mysterious particle which even an iron plate of such great thickness cannot stop, is now attracting the attention of scientists the world over. It goes without saying that because of its specific properties the neutrino stands somewhat apart among the elementary particles. Until the existence of the neutrino became known the electron was considered the smallest of all the elementary particles. But the neutrino is at least 500 times smaller than the electron. The existence of such an extraordinary particle was predicted as far back as the nineteen thirties by the Swiss physicist Pauli. He studied the so-called beta-decay of radioactive elements, and found that such substances emit electrons or positrons and at the same time lose some other particle of energy. Pauli assumed that this particle of energy is carried away by some new substance as yet unknown to science. This was the elusive neutrino which Bruno Pontechorvo succeeded in catching despite its incredible evasiveness.

Not only Pontechorvo, but other scientists as well, particularly the American physicists Reines and Cowan, confirmed in an experiment the theoretical calculations according to which the neutrino should be absorbed by a proton changing into a neutron, in a process which may be contrasted to beta-decay. These investigations confirmed the existence of the neutrino.

Pontechorvo proved that such a process can be predicted: if a ton of hydrogen, whose nucleus is the proton, is bombarded with neutrinos in an atomic reactor, there will be about one hundred proton-to-neutron changes per hour, involving the absorption of neutrinos.

And, of course, when the existence of the neutrino became a fact, it turned out that all the matter of the universe is permeated with these particles which fly in all directions at the velocity of light.

Our Sun is an immense source of neutrinos. It emits such a huge amount of these elementary particles that if we possessed a special kind of vision, we could see tens of thousands of millions of these particles flying through our palm each second.

How enormous, then, must be the number of these particles penetrating the globe!

Naturally, the idea occurs: is there no way of seeing what processes occur when the neutrino is retarded by the Earth and its separate geospheres? Maybe this would give us some new information on the structure of the inside of the planet? Maybe seismometry of the planet, analysis of all the vibrations of the Earth due to natural and man-made explosions, can be replaced by a sort of neutrino "seismometry", if these two essentially different words can be so combined.

Such neutrino "seismometry" is evidently already a thing of the near future. Perhaps analysis of the behaviour of the neutrino in the various geospheres will bring us knowledge of the state of matter in the Earth's mantle and

its core. And then we shall be able to understand the geological processes that take place in the depths of our planet.

First Results

So what does the Earth's information tell us? How do we picture the inside of our planet today?

There is a popular toy sold in Russian souvenir shops, called the matryoshka. When you open it you find another matryoshka inside, only a little smaller. You take it out, look it over, open it, and find a third one, a fourth, a fifth, and a sixth. Finally, at the very centre of the toy you come to a minute matryoshka.

Our planet is in a sense comparable with this amusing Russian toy. If we could lift the Earth's crust we should see the mantle of the Earth. To some extent the mantle copies the shape and outlines of the Earth's surface. Whatever layer of the mantle we opened after that, it would also resemble the overlying one in some features, whether it is the Guttenberg or the Golitsyn layer. Then, raising the mantle, we should see the Earth's outer core. It also must copy the surface layers. Finally comes the inner core, the very heart of our planet.

But the Earth is no matryoshka, and is not so easily opened. That is why we still know very little about the inner geospheres, only what the various information kindly placed at our disposal by the planet, tells us.

We get a lot of ideas when we decipher the gravity code after weighing the surface and

inner zones of the Earth. Magnetic information has also given us a large number of interesting facts concerning the inner structure of the Earth. But so far we have been unable to coordinate the data of the magnetic information code with those of the gravity code and the seismic wave code. And this is so despite the fact that we have obtained much additional data from analysis of the pressures calculated for the various geopsheres and from analysis of stray electric currents.

Yes, the information code is as yet incomplete. We have not learned to generalize data, and to decipher radioactive signals. We can only conjecture as to what we will obtain from the information we will receive from certain elementary particles such as the neutrino which permeate the whole Earth. We have not yet learned to decipher other kinds of information, and we are probably unable to pick up all signals. Maybe the answer to the questions of the inner structure of the Earth, of the processes that take place in the depths of our planet, is somewhere here, right beside us, but we keep passing it by. Was it so long ago that we began to notice magnetic or radioactive signals and to decipher them!

But there still remains a lot to be cleared up. We have already abandoned, as unscientific, the hypothesis of the molten layer beneath the Earth's crust. These ideas, which were widespread at the dawn of development of geological science, are now supported by hardly any scientists, though they are still popular among non-experts.

We know that both the mantle and the matter concealed beneath it are in an unusual state, unknown on the Earth's surface. This state is due to the tremendous pressures existing in the depths of the planet. Inside the Earth, according to calculations, matter acquires metallic properties owing to the possible disruption of the electron shells of its atoms.

But none of this reasoning has as yet been confirmed by hard facts. And here the conclusion is self-evident. We must drill! We must penetrate into the substance of the Earth's mantle. Then many of our hypothetical constructions will fall to pieces and science will be enriched with new facts.

From Outer Space into the Depths of the Earth

"The sky was all aflame. A boundless transparent haze blanketed the vault of heaven. Some invisible force made it flutter, and glow with a dainty violet light. Here and there bright flashes appeared and immediately grew paler as if clouds made of pure light were born for a moment and then dispersed. The stars shone brightly through the haze. Suddenly the haze disappeared. Violet clouds flashed again at some points. For a split second it seemed that the lights had gone out. But then long rays, gathered in places into bright beams, began to quiver ... with a pale green colour. Now they tore away and rushed with lightning speed to the zenith. For a moment they remained

stock-still up above, forming a vast continuous canopy, then they shuddered and went out."

Such is one of the picturesque descriptions of the event commonly referred to as the Northern Lights. It is that given by G. A. Ushakov, an explorer of the North, in his book *Over Lands Unknown.* Just as exalted a description of the Aurora Borealis was given by Fridtj of Nansen.

Any book by an enthusiast of the North contains a description of pulsating uniform bands and ribbons, of splendid multicoloured curtains and draperies or immobile fiery glowing arcs which keep changing colour each second and even more frequently. Anyone who has seen the Aurora Borealis can never forget this wild chaos, this fiery flow of luminous matter.

The artist G. N. Gamon-Gaman who studied the distribution of colours in the Northern Lights says that it is impossible to describe this fairy-tale play of rays illuminating the gloomy dark fjords on the coast of the Barents Sea.

"...Multicoloured rays," writes Gamon-Gaman, "darted arrowlike from the zenith and as if in battle kept overtaking and extinguishing one another and then appearing anew in another part of the sky, flaring up even brighter than before and again flying apart in coloured zigzags all over the north-eastern section of the sky. Suddenly this gigantic trembling sea of colour grew dim and dark violet and blue gaps appeared in it.

"The sky grew dark, but soon an emerald glow appeared from the inky blackness in a bright halo occupying a still greater area of the

heavens and passing into a vast flow of light waves. The whole sky flared up in red flame, whirlwinds, splashes of fire, trembling shafts, fluttering sparks, fiery columns, and dancing gleaming arrows. A multicoloured mist streamed forth resembling some fiery monster, or wings of fire and mother-of-pearl dust. This entire mass of colour and lustre combined into an integral heavenly bonfire.... Yes, it was a magnificent display of cold fire in the sky."

Such are the signals that come to us from outer space. A definite relationship has been established between magnetic disturbances, magnetic storms and the intensity of the Aurora Borealis. An immense flow of corpuscles flying into the Earth's magnetic field creates the play of colours just described.

The magnetic field extends 70 thousand kilometres outwards from the Earth's surface in all directions. It is this field that traps the streams of electrons, protons and other cosmic particles that come in at mad rates from the outer reaches of the Universe. It was established recently that the Sun is not the only source of cosmic radiations. A large amount of cosmic particles come to us from the centre of the Galaxy, and from many of the zones of the so-called radio-nebulae, hot nebulae. Some galaxies are also noted for very active cosmic radiation. For instance, an intense stream of cosmic particles comes to us from two of the galaxies in the constellation Cygnus. Some astronomers believe that this is due to a collision of two galaxies in that constellation; others think that it is the birth of galaxies that causes the

stream, and there is reason to believe that the second assumption is closer to reality.

Primary cosmic particles do not reach the Earth's surface. When they come into the Earth's magnetic field and collide with elementary particles and atomic fragments in the upper layers of the atmosphere, they give birth to a whole cascade of secondary cosmic radiations consisting of such elementary particles as measons, hyperons and many others. Most of them attach themselves to the invisible spirals of the Earth's magnetic field. Only a small portion succeeds in passing through to the next zone of the magnetic field; here there is another avalanche cascade of elementary particles, they again fall into a magnetic trap and only a small number finally reach the Earth's surface.

Some of the atomic fragments which find their way to us from other galaxies possess such high energies that they cause showers of secondary cosmic particles covering areas of several square kilometres.

What else do the emissaries of outer space tell us? Will we ever be able to decode all these signals and their reflections caused by the Aurorae?

I think we will. It is a fact that our Novosibirsk mathematicians and archaeologists succeeded in deciphering the writing of the Mayas. This was done with the aid of electronic computers. With their help signs whose meaning was thought to have been lost forever, began to speak. And there will come the time when ultramodern electronic computers will decipher the voices from outer space. Already the traces

of cosmic particles tell us of great events taking place in the life of stellar and interstellar matter. And some day outer space will become an open book in which we will read, perhaps, of the life of distant worlds. It is to be expected that the contents of that book are abundant and diverse. Maybe its pages contain information on the various parts of the Galaxy, and the voices of those who are trying to communicate with the intelligent creatures inhabiting the Universe?

It occurs to me that perhaps the writer I. A. Yefremov was right in his book *Andromeda* when he wrote about the "Great Ring" for radio communications between the civilizations of many, many planets inhabited by intelligent creatures over large regions of the Galaxy. So far, as we know, the investigation carried out by the astronomer Drake in 1960 of the radio radiations of the stars Epsilon Eridani (Azha) and Tau Ceti, only eleven light years away from us, was unsuccessful. Drake was obliged to admit, to his regret, that all his efforts to hear the voices of intelligent creatures had so far been in vain. But he examined only a small part of the space around the solar system, while there may be intelligent creatures at some distance from the Sun.

Scientists think that the most convenient waves for transmitting messages are ultrashort ones about 21 centimetres long. This is the wave-length of the famous radio line of free hydrogen, the chief element of the Universe. With the aid of radio telescopes we are constantly probing outer space on this wave-length.

And it is not impossible that one day we shall hear the voices of our intelligent brothers in this band.

Some of the voices of the Universe have already been deciphered. We know that the radio waves that come to us from the central parts of the Galaxy are due to gigantic nuclear explosions. We can even cause—on an incomparably smaller scale, of course!—phenomena similar to these cosmic catastrophes.

A group of scientists who were studying the equatorial region in the district of the Apia Observatory on the Samoa Islands once observed the Aurora at a time when there were neither magnetic storms nor major disturbances of solar activity. It turned out that an American thermonuclear bomb had been exploded the same day and hour three and a half thousand kilometres away from the observatory over Johnstone Island, and this powerful source of radiation had caused the artificial Aurora.

Still more intense artificial Aurorae were observed on the Hawaiian Islands and in New Zealand during the powerful superhigh-altitude explosion carried out by the Americans in 1962. At the moment of the explosion a red, orange and pink luminescence appeared at a great height. What a mighty force is this in the hands of mankind; nature herself is giving us warning of the great hazard of radioactive radiation. Cosmic particles have been established to be fatal to animals and plants. If the Earth had no magnetic field and thick atmosphere life could hardly exist on the surface of our planet. Radiations are destructive to the human organism.

Nature set up a shield against the menacing force of outer space, and it is intolerable that the same hazard should be created here on Earth. That is why the peoples of the world so gladly received the news of the conclusion of the Moscow Treaty prohibiting nuclear tests.

At the same time, we hardly know anything about how the Earth's magnetic field affects living creatures. It is known only that some organisms are very sensitive to it. For instance, certain plants turn their stems towards the magnetic poles when germinating. Biologists have succeeded in developing conditional reflexes in some animals to a magnetic field. Recent observations have shown that the condition of sick people becomes worse during magnetic storms; this is especially true of people suffering from hypertension, tuberculosis and cardiovascular disorders. There is other data demonstrating the effect of the magnetic field on the life of organisms.

Do the magnetic field and cosmic radiation have any effect on the rocks in the Earth's crust, in its mantle and even in the core? The substance of the core is evidently in a state in which the outer electron shells of the atoms are disturbed. This fourth state of matter, viz., plasma, is encountered everywhere in space. The three states of matter familiar to us—solid, liquid and gas—are rather a rare exception there.

Above our Earth, in the uppermost part of the atmosphere, in the zone of the magnetic field, electrically charged particles are moving. Among them are many fragments of atoms or

separate elementary particles. Interstellar matter consists of plasma. This celestial plasma can be compared with what we observe in ordinary gas discharge tubes which illuminate our streets and shops and create the fantastic multicoloured play of city lights. There is a stream of electrons moving there too. The entire process often occurs at a very high temperature running into tens of thousands of degrees. But take one of these tubes in your hand and you will find it is cold. This cold gas-discharge light is generated by matter in the fourth state, an infinite ocean of which encompasses our planet.

Inside the Earth is matter that formed under immense pressure, and of course it must react to all the processes occurring in the magnetic field of the Earth.

Here is how we picture the magnetic life of plasma. On the Sun, either in the zone of its core, or in the space surrounding it, sharp compressions alternate with sharp expansions giving rise to changes in the magnetic field. The Sun is encircled with a sort of cyclotron in which cosmic particles are accelerated to tremendous speeds by these changes in the magnetic field.

An analogy could be drawn here with the proton synchrotron installed at Dubna near Moscow. There elementary particles are speeded up in a vacuum by means of an electromagnet with a core weighing 36 thousand tons. But the Sun is immeasurably more powerful. Accelerated to enormous speeds by its magnetic field, cosmic particles fly out into the peripheral zone and reach the magnetic field of our Earth. And

then cosmic particles of the second, third and fourth "generations" penetrate the Earth either at the poles where the bundles of lines of magnetic force converge, or at the "spurs" which connect the magnetic force fields with the large magnetic anomalies.

And the Earth can hardly be indifferent to these penetrations. We have seen that during strong disturbances on the Sun magnetic storms occur on Earth. We have also seen that the Earth even changes the course of its rotation about its axis under the influence of magnetic storms.

Probably the particles that penetrate the Earth act on the plasmic zone inside our planet. They may excite the plasma and may generally interfere with the operation of its natural "dynamos".

It is quite possible that the intensive penetration of cosmic particles into the plasma of the inner zones of the planet changes its magnetic field, and hence, not only the retardation of the Earth, but also the upsurge and downthrust of individual parts of the Earth's crust.

If we accept the hypothesis of Wegener or Staub, relating the birth of mountain ranges with the shift and collisions of the continents, we find a direct relation between the processes occurring in outer space and the geological life of the Earth.

Powerful magnetic pulses may result in faulting of the Earth's crust, shifting of separate rocks, and folding. If we explain the usual course of folding in the mobile zones by collision between these rocks, one of the sources of

their movement, thought by many to lie simply in their mechanically drawing together, may be precisely cosmic forces.

Perhaps we have here the causes not only of folding, but of other regularities influencing the life of our planet? Perhaps one of the effects of the penetrating radiation is to enhance the radioactivity of rocks and to give rise to new magmatic hearths?

The laws of magma splintering then come into force—the laws of formation of separate rocks, minerals and accumulations from this magma.

It is not impossible that magnetic pulses affect the movement of oil and gas from the depths to the Earth's surface. These are all only assumptions, but if they turn out to be right, many mysteries will be cleared away, and many complex problems solved.

The Earth is not an isolated body, but is part of the Universe and is subject to all its influences. We have seen that stray electric currents arise in the Earth as a result of magnetic storms. We cannot but take into account the electrochemical reactions that result from the passage of electric currents through rocks. Especially pronounced changes occur when the rocks are flooded. The brines found on Earth are natural electrolytes. But the course of natural electrochemical reactions has not been sufficiently studied as yet.

What laws about changes in rock do we usually take into account?

When we heat rocks under conditions close to those of a magmatic hearth we get marble

from limestone. If we subject the same rocks to great pressure we again get marble. Similar phenomena occur in nature. Then we have a clear idea of the part played by subsoil water which removes a great variety of substances from the rocks and replaces them with a no less great variety of others. We involuntarily seek for the channels by which the substance was carried off and by which it was brought in, even if this mode of formation of rock has been proved impossible.

And what if there actually were no such channels? This is where a great deal of controversy arises. It is quite possible that electric currents, radioactive rays and cosmic particles penetrating the rocks cause definite changes.

How, for instance, do cosmic particles affect rocks? We know already (and some of the methods of geophysical prospecting are partially based on this) that if a rock is irradiated with a strong source of radiation a definite quantity of isotopes forms and accumulates in it. But if we can bring about these reactions under artificial conditions, using relatively weak sources of radiation, it is not difficult to imagine that nature can cope with similar experiments on an immeasurably larger scale.

Findings of transuranic elements under natural conditions are no longer a novelty to investigators of uranium minerals. We know, for instance, how plutonium, one of these transuranic elements, is produced. It forms when nuclei of uranium-238 are irradiated with neutrons. In nature neutrons may come in from outer space. A stream of such cosmic par-

ticles may act on uranium-238 to form plutonium-239. Besides the latter, curium-247 and americium-243 have also been detected. The lifetime of these elements is relatively short. The half-life of americium, the least durable, is only about nine thousand years.

An ancient Katangese legend has it that many, many years ago a celestial fire descended upon the Congo. This fire gave birth to the precious metals which were found afterwards in various parts of Central Africa. Of course, this is a legend, and we cannot draw any conclusions from it, but is there not a grain of truth in it? Would it be wrong to assume that some of the stone deceivers, or stone-werewolves, which have retained the finest sculptural features of the original substance, resulted from radioactive processes of transformation of chemical elements?

It is quite possible that some day man will learn to control the processes of formation of ores and mineral accumulations by means of directed nuclear shocks. This is only a dream at the moment, of course, but very many science fiction forecasts have come true in the long run. Scientific publications have already begun to appear on this subject. In a paper on the rocks of the central Ukraine O. I. Slenzak of Kiev attempts to prove that part of these rocks originated due to the action of atomic reactions.

Similar investigations have been made by the American scientists Seaborg, Pearlman, Hollander and others.

Slenzak and the American scientists have many opponents. It is difficult to abandon the

habitual ideas of overheating, pressure and the action of subsoil waters on rocks, but there will come a time when the new ideas are borne out by a sufficient number of facts. Then these assumptions will pass from the realm of science fiction into the realm of practical science. Perhaps establishment of the uniformity of the vital processes of our planet and the Sun will give rise to a new theory of the origin of the Earth and the geological processes that take place on it?

So far the mantle conceals the mysterious core of the Earth. There are many different hypotheses and assumptions about what it hides. But when the information coming from the deep-seated zones of the Earth is decoded more fully, the exchange of messages between the depths and outer space will doubtless open new pages of the exciting history of the development of our planet.

In Search
of the Unknown

Failures at First

The whole world first began to talk about the remarkable Moho project in 1957.A super-deep drill-hole which was to pierce the Earth's crust right through to the mysterious mantle, had up till then been considered only in the depths of U.S. research institutes. When I first read of this project in an American magazine I immediately recalled our argument at the XVII International Geological Congress. The Americans wrote that they would penetrate into the substance from which all the rocks of the Earth originated. It followed from these words that the substance of the mantle intruded into the Earth's crust in a molten state. It was not difficult, therefore, to guess that the project was headed by a typical magmatist who supposed that the Earth's crust covered a peridotite melt.

I was anxious to find out who was heading the project. Maybe they had been with me at the XVII International Geological Congress in 1937? Their names were published later; the drilling operations were to be carried out

under the leadership of Alan Waterman, D. Sc., Director of the U.S. National Science Foundation, while Detlev W. Bronk, President of the Research Council of the U.S. Academy of Sciences, was entrusted with the scientific part. I immediately looked up the directory. No, they had not been at the Congress. But the ideas we had discussed so enthusiastically at that time hung in midair, so to speak.

The project did not take shape for some time. It was displayed publically for the first time in 1959 in New York where scientists from all countries had gathered for the Oceanographical Congress. The Soviet delegation arrived on the *Lomonosov*, a vessel that had more than once crossed the Atlantíc Ocean.

At the exhibition organized in connection with the Oceanographical Congress the Americans showed that they were going to drill two experimental holes, one in the vicinity of Guadalupe Island in the Pacific Ocean, and the other near Puerto Rico, in the Atlantic. Before beginning these holes they were doing some test drilling in the ocean floor from on board ship. But now something really great had been planned. Scientists were unanimous in the opinion that very little was known of the substance that would be encountered during super-deep drilling.

At Guadalupe Island it had been established by seismic investigations that the ocean floor lies four kilometres below the surface of the ocean. It was expected that there would be about 150 metres of loose sediment here, after which the hole would cut into the solid rock

bottom and would penetrate into it as far as possible. In this area the base of the Earth's crust lay 9.5 kilometres below the surface of the ocean; in other words, the entire crust of the Earth here had a thickness of only 5.5 kilometres. A mere five and a half kilometres separate us from substance typical of the Earth's mantle! Naturally, everybody agreed that the main thing was to get results as soon as possible.

The subsequent march of events was as follows. At the Assembly of the International Union of Geodesy and Geophysics in 1960, a committee was organized for investigating the upper mantle of the Earth, headed by the president of the union, Prof. V. V. Belousov, Cor. Member of the U.S.S.R. Academy of Sciences and a great expert on the Earth's structure.

Soon the project went into action near Guadalupe. The Americans chose a rather risky variant. Up till then they had drilled the experimental holes from anchored vessels, but here this was impossible. The vessel—a raft from which the drilling was done—could not drop anchor at a depth of four kilometres. Such an anchor could not have kept the vessel stationary anyway.

And so a different idea was suggested. Screws were situated at the four corners of the raft, controlled by an automatic unit which switched on one or another of them as soon as a shift became noticeable. The entire unit was oriented in space by means of several buoys arranged around it.

Drilling began in March, 1961, and by April the first data were obtained. The ocean depth in this district was found to be slightly less than expected, 3,570 metres instead of four kilometres. The diamond drills first went through 150 metres of loose sediment on the ocean floor (in this case the calculations were right), and then the drill cut through solid rock to a depth of 36 metres.

After the rock from this depth was raised to the surface the whole unit practically went out of order. It was impossible to get back into the same hole, and drilling had to be discontinued.

The same thing happened in the vicinity of Puerto Rico, where the hole was lost because of a terrible storm which moved the raft despite all the ingenious devices.

The Moho project was not accomplished, though some interesting geological data were obtained. These data were given finishing touches by Soviet research workers.

After the fragment of basalt was lifted from the ocean floor the Americans sent pieces of this rock to many of the national academies of the world. One of them was addressed to the Academy of Sciences of the U.S.S.R.

Academician D. I. Shcherbakov immediately handed this rock over to research workers, and they confirmed the accuracy of the determinations. The rock was found to be basalt, as indicated, or more precisely, augite-basalt, as it is called. But the most interesting point is that its absolute age was determined. It was found to have formed 212 million years ago

(the accuracy of determination being plus or minus 10 million years, which is quite good for such a geological period).

This brought back to mind the hypotheses put forward by different scientists, concerning the structure and origin of the bed of the Pacific Ocean. According to the German scientist Staub, this was the part of our planet from which the Moon was torn away. It happened at the dawn of the Earth's history, more than 2,000 million years ago. A kind of wound formed in the body of the planet. Later basalt lava came up from the depths of the Earth and healed the wound.

The fact that basalts actually were discovered seems to confirm Staub's hypothesis, but their age was very small from this point of view. And judging by the data available to modern science, at that time no event could have occurred which might be interpreted as such a tremendous catastrophe in the life of the Earth as the detachment of a huge body like that of the Moon.

Another idea that seems just as doubtful is that of L. A. Pukhlyakov. According to his calculations the Earth's second satellite, Perun, fell onto the surface of the planet in the region of the Pacific Ocean. This happened 50 million years ago. But geologists have found no traces of this catastrophe.

The American scientists were unable to accomplish their grand project. They have declared that they intend to drill a new hole in the district of the Hawaiian Islands, in the very centre of the Pacific Ocean.

Geography of the Unknown

Preparations have long been under way in the Soviet Union for organizing deep drilling in various parts of the country. Soviet geologists decided to take a different path. Complicated calculations of super-deep drilling were made. A great deal of work was done by way of state seismic probing over the boundless territory of the Soviet Union.

Seismologists revealed the main features and even structural details of the Earth's crust in many parts of our country, both on land and in the depths of the sea. Observational techniques were perfected. Now convoys of vehicles, including special-purpose buses, trucks and cars are encountered in many places. Some of these bear a red flag. In the language of traffic signs it means: "Dangerous fuel or explosives. Pass or overtake with care!" And indeed, these trucks carry explosives intended to create artificial earthquakes.

Other members of this convoy are self-propelled drilling rigs or just drilling rigs. When they reach the site of observation they drill a central hole which is charged with explosive. And then seismic pick-ups, sensitive devices which register all the tremors of the Earth, are lowered into 48 smaller holes.

The seismic pick-ups are connected to the central control bus. There each signal is converted into a fine beam of light incident on a wide roll of photosensitive paper tape. The 48 light pencils leave their traces on the paper and thus tell the investigators how the seismic

ray was refracted or reflected by the various rocks. A seismogram is recorded on the tape. The uninitiated can make neither head nor tail of the dense pattern of lines. But an experienced geophysicist will immediately spot the point where the waves entered this or that layer, and the point where they were reflected. He will also see the depth of occurrence of the layer and the zone below which the rate of propagation of the seismic waves rises sharply; the Mohorovičić discontinuity, the lower boundary of the Earth's crust.

Seismologists are the pioneer pathfinders of the Earth. In their wake come other investigators who plan the points at which deep and superdeep holes are to be drilled. One of the chief leaders of this work in the U.S.S.R. was Professor Y. N. Godin. He was an ardent enthusiast and devoted his whole life to the study of the structure of the Earth's crust with up-to-date equipment.

There is a remarkable picture in the Museum of Earth Science on the 28th floor of the Moscow University, showing a latitudinal section through the Earth's crust right across the Soviet Union. This drawing was made by Ass't Prof. V. A. Aprodov, who works at the museum. In compiling the section use was made of material collected by Godin and his co-workers, as well as by other scientists who studied the structure of the Earth's crust. It is not by any means a simple drawing. It is based on detailed scientific investigations and reveals the great variety of structural types in the different parts of the Earth's crust.

The Earth's crust varies even within the bounds of the European part of the U.S.S.R.

and the Urals. It is entirely different in Western Siberia. The part between the Yenisei and Lena rivers is similar in structure to the European part of the U.S.S.R. In the east of the U.S.S.R. we find yet another type of structure with the roots of folded mountains reaching deep down into the Earth's crust. Then follow more and more distinct traces of the struggle between land and sea. The contour of the continental crust of the Earth is abruptly cut off and gives way to ocean zones where the granitic layer is missing and the basaltic layer comes close to the surface. The Earth's crust becomes slightly thicker in the island zone, and then further on, at the bottom of the ocean, it becomes thinner and thinner.

If we examine the other parts of the Earth's crust we encounter specific features everywhere, in each district. A curious profile is that running through the Black Sea and the Caucasus. The Caucasian Mountains themselves do not differ in any way from the continental parts of the Earth's crust. The crust is about 40 or 50 kilometres thick at this point, and there is a sedimentary layer, a granitic one and a basaltic one. In the Black Sea region a transition is observed to the oceanic type of structure of the Earth's crust, but there are also noticeable differences.

They consist primarily in the fact that the thickness of the Earth's crust here is neither five, ten, nor twelve kilometres as in the ocean, but all of twenty. The sedimentary layer is very thick (over ten or twelve kilometres) while in the ocean it is comparatively insignificant;

the granitic layer is almost or totally absent, being found only as small islands. Then comes a basaltic layer five to eight kilometres thick. And under it lies the upper part of the Earth's mantle.

It would seem that all that has to be done to outline the site for drilling a hole is to mark a point on the map. But in order to mark that point a large cycle of various observations must be carried out. The point has to be selected so that it will give the maximum returns. What was the key factor in taking the decision to organize five 15 to 18-kilometre drill-holes in the Soviet Union? It was mainly the national-economic significance of this kind of work.

Of course, in taking this decision many scientists crossed swords. The discussion concerning the exact sites of the holes is not over yet, but the regions of deep drilling have been outlined approximately.

The stories of these holes are best told by the rocks themselves. Stones silently hold information about the conditions of their origin, about the complex events they experienced, and about the problems connected with them. Stones can also reveal to us the general aspects of the geography and geology of the unknown, of that which is still hidden from us.

There are a few specimens in my collection of stones that I value especially highly. They are sometimes nothing much to look at, but differ from their brothers in features that are more important than appearance. Each of them has its own story. Indeed, a story with a fascinating subject. Even a simple cobblestone

can tell the investigator a story full of tragic emotions, and some time I shall write a story about a cobblestone. To the geologist stones are like people. Their fate also depends on their character, on vicissitudes and even on chance.

Take, for instance, the beautiful diamond with its gleaming facets. In the Marshal's Star the gem's lustre sings the military valour of its bearer. It cuts through the strongest rocks, shapes thousands of machine elements, helps to make the finest wires, and works in the bearings of the most delicate chronometers. Under different conditions the diamond leaves murder, treachery, and blood in its wake.

The Koh-i-nor gem is dazzling. But how many crimes are connected with this stone! It is said to have been found in India five thousand years ago and to have passed from one rajah to another. Scores of crimes were committed to possess it. They say that not one of its Indian owners died a natural death, at least for the last five hundred years!

The Akbar Shah diamond rests now in the Hermitage Museum in Leningrad. It was given to the tsarist government as a reward for killing the writer Griboyedov who was then the Russian ambassador in Teheran.... And how many black deeds other such stones carry in their memory!

Then there are stones of a different destiny. They do not shine, nor gleam, nor show any play of sparking colours. But it is as if the life of many people were focussed in them. Their fate is interesting; they are witnesses of great events in the history of the Earth. These are

stones from the regions where super-deep holes are to be drilled.

The First Stone Tells Its Story

The first stone is from a deep drill-hole in the Bashkirian Pre-Urals. It lay under a two kilometre layer of rocks. And when it was lifted out of the depths it turned green as if with rage at those who had dared to disturb it. Greenish black, it somehow resembled an Arabian jinni. The only difference was that it neither shouted nor threatened. On the contrary, it would tell nothing about itself.

And so, the scientists decided to cross-question this unruly jinni. Modern investigators know many ways of forcing even a stone to speak.

To begin with, the scientists cut out of the stone's body a plate, or section, as it is called, two hundredths of a millimetre thick. Such a plate is transparent and can be conveniently examined under a microscope. Under the geological microscope the jinni showed a play of hundreds of halftints. Its colour began to vary from dark green to a pale venomous greenish yellow. These halftints are well known to geologists. They are characteristic of a mineral called hornblende or amphibole. And among its green spots the outlines of feldspar could be readily discerned; this mineral betrays itself by its striated dark and light crystals.

Whether he liked it or not, the jinni was no longer nameless. He was obliged to admit

that he was called amphibolite, after the principal mineral. And now, seeing that his name was no longer a secret, he suddenly began to talk, using high-flown language in contrast to the archaic speech of the Arabian jinni: "We amphibolites are rocks distributed throughout the world. We can be ortho-rocks—apogabbroic, apodiabasic; and para-rocks—apomarlaceous; and mixto-rocks—apolimestones with major additions at contacts with magmatic rocks."

Even the geologists were surprised to hear such a speech. They demanded that the amphibolite jinni should retell all this in Russian.

It appeared that these polysyllabic words concealed an important meaning. The jinni was disclosing the mystery of his birth. Translated into everyday language the sentence he had uttered meant that not all amphibolites owed their origin to coexistence with the red-hot, molten, fiery-liquid masses of magmatic hearths, as many geologists believe. "No," said the amphibolite jinni, "we amphibolites can also come from sea ooze." This put the geologists on the alert, and they continued the crossquestioning.

Here it became necessary to resort to geophysical instruments. The interrogators, i.e., the scientists, were obliged to go out to the place where the jinni was extracted. They had to cover many hundreds of kilometres with their instruments. But as a result it was found that amphibolites, as well as many other rocks associated with them, occur here, under the earth, differently from other Ural rocks.

What are the characteristic features of Ural rocks? First of all, they are drawn out along

the meridian. The Urals, we were taught in childhood, are a mountain range that stretches from the Kara to the Aral Sea. But the rocks intimately associated with the amphibolite jinni were drawn out in a latitudinal direction, crossing the Urals at several points in the form of chains resembling mountain ridges! The latitudinal Ural Mountains crossed the meridional Urals as if no Ural Mountains existed at all.

This is where the important confession made by the amphibolite jinni under the microscope came in. So, what was discovered under the ground were not internal intrusions of the type of magmatic hearths, but traces of typical rocks that at one time formed on the surface and were now buried at great depths. Therefore, in the distant past the site of the ancient Ural Mountains was also occupied by a sea in which sediments accumulated. When was all this?

Two Soviet scientists, Lenin Prize Winners Academician A. A. Polkanov and Prof. E. K. Gerling, developed such methods of interrogation that the rocks were forced to tell their ages whether they wanted to or not.

And so the amphibolite jinni fell into the hands of M. A. Garris, Candidate of Science, a worker of the Bashkirian Branch of the Academy of Sciences of the U.S.S.R. And what did she not do to him! She ground a piece of the stone into a fine powder, soaked it in acids, heated it and performed hundreds of other operations. And the jinni gave way. He disclosed the mystery of his birth to the scientists.

He was born exactly one and a half thousand million years ago! This figure took everybody's

breath away. Scientists had been certain that the most ancient Ural rocks were much younger, not more than twelve hundred million years old!

But this jinni was not the oldest one. Many of his friends were born ever earlier. Prof. L. N. Ovchinnikov of a similar laboratory in Sverdlovsk discovered rocks nineteen hundred million years old! Rocks of such an age were found in a drill-hole in Krasnokamsk, where they had hidden themselves at a depth of twenty-nine hundred metres below the Earth's surface.

The jinni from Krasnokamsk told (also through geophysical instruments acting as interpreters) that they stretched out as a long mountain chain almost from the town of Kirov to Khanty-Mansiysk in the middle reaches of the Siberian river Ob. That is a distance of almost two thousand kilometres. In other words, this underground range is almost as long as the Urals!

Thus, the jinni made geologists get down to a study of the deep-seated Urals. But as to the main question, what minerals may be contained in these buried underground ranges, we have not as yet obtained the answer. The questioning of the ancient jinni continues.

Scientists know that in all countries of the world rocks almost two thousand million years old display rich accumulations of iron and copper ores; they also contain ores of rare metals and many other valuable minerals.

The interrogation of the jinni was recently taken over by scientists called tectonists. These geologists study the laws of formation of the Earth's crust and the history of its development. The tectonists established that the latitudinal

Ural Mountains are situated at various depths. For example, the part of the latitudinal ridge between Kirov and the Chusovaya River runs at depths of five or six and more kilometres. But in the middle Urals this ridge was broken up by ancient earthquakes to give separate blocks located at various depths. Some of the blocks come close to the surface. One of them is supposed to be in the vicinity of the town of Nizhny Tagil. Similar highly raised blocks of the buried Urals may be encountered also in the Trans-Ural part of the latitudinal range.

Soon the nameless latitudinal Ural ridge will be able to receive a name. For the time being it is referred to as the Third Urals. The First Urals is the mountain system running from the Kara Sea to Mugojar, and the Second Urals is the name given to the buried Trans-Ural ridge which stretches parallel to the first. But the latitudinal range is the first by birth and should be number one. A considerable part of it passes through a territory which was called Biarmiya in the past. It was a little larger than the present-day Perm Region. By the way, "Perm" comes from the word Biarmiya (that is what this land was called in the 9th to 12th centuries). The name Biarmiya could be given to the latitudinal Ural range, making it the Biarmiyan Range. It could be divided into the Biarmiyan part proper, the one in the Pre-Urals that runs from Kirov to the town of Chusovoi, the middle part, in the Urals proper, which might be called the Tagilian, and the eastern end which might be called the Mansiysk subterranean upland.

Such a word combination looks rather strange: subterranean and then upland. But the upland was once on the surface, and was buried only as a result of the complex processes of the very long history of our Earth.

Of course not everything here is unquestionable either. Some geologists and geophysicists think that no such range ever existed, that the thick masses of dense, magnetic rocks were magma that intruded into the crust from the zone of the Earth's mantle along deep-seated faults, and solidified there. But apart from how the rocks of the Biarmiyan Range originated, much interesting data on the minerals they may contain is to be had by drilling through them.

Imagine that 10 or 15 years have passed and the Urals super-deep hole is finished.

We have obtained the answer to many questions. Some of them are connected with the rocks that intruded here from the Earth's mantle, or, according to a different hypothesis, formed here from ancient sedimentary rocks. According to conceptions that have long been existent in the Urals, all its granitic rocks are considered to be what is known as batholites, huge cone-shaped intrusions from the zone of the Earth's mantle. It was thought that here the Earth's crust had been melted through and through. But that was what the magmatists thought. The neoneptunist-transformists say that there were no great fusions of the Earth's crust, that all the Ural granites are arranged as sheet-like deposits, called harpoliths, and that they formed due to fusion of the rocks that existed right there,

in the same layer. Or maybe there was no fusion at all, and part of the rocks simply became granitized owing to a certain rise in temperature and high pressure during mountain building processes; clayey sands changed into granites. Geophysicists who study the zones of granite occurrence in the Urals even name the depth and thickness of these harpoliths.

The geophysicist A. A. Kuznetsov, Cand. Sc. (Geology and Mineralogy), reckoned up that in the South and Middle Urals granitic harpoliths are not more than one and a half or two kilometres thick and are underlain by sedimentary rocks again. These calculations refute the predominant idea that everywhere on Earth a sedimentary layer should come first, followed by a granitic layer and then by a basaltic. Here it is entirely different: first a sedimentary layer, then a granitic one and then again a sedimentary one! Considerable corrections must therefore be introduced into the general scheme of the structure of the Earth's crust. And if this is so, another curious phenomenon must be taken into account: the greater the depth we reach with our drill-holes, the less changed (metamorphozed) rocks we encounter there. This means that under the granitic harpoliths there may be unchanged sedimentary rocks with all the minerals characteristic of them. And most sedimentary rocks contain petroleum and mineral coal. Thus, while we are searching for oil along the Volga or in the West-Siberian lowlands in the Trans-Urals to supply the Urals industry, there may be petroleum right in the Urals! Possibly, there are great accumulations of petrolium somewhere

beneath Nizhny Tagil, Sverdlovsk, Magnitogorsk, Orsk and many other large industrial centres. If we find them we shall be able to supply the Urals with its own oil or mineral coal, which the Urals industry needs so acutely.

Coal is brought to the Urals from Karaganda and the Kuznetsk Basin. A railway line is now being laid northwards along the eastern slopes of the Urals in order to supply the Urals industry with coal from the North Sosvinsky Basin and Vorkuta on the west slopes of the polar Urals. This is a long distance and will be expensive. And what if coal lies right under the Urals?

If traces of oil products are discovered in the depths as a result of super-deep drilling, this will cause a veritable revolution in our ideas of the reserves of mineral fuels in the Urals. Of course, one hole is not enough to solve all these industrial problems, but it can set important tasks before science and practice. And this is already sufficient to justify all the costs of super-deep drilling!

One more important problem. If a hole is sunk in the vicinity of Tagil it will pass the Konrad discontinuity between the granitic and basaltic layers, because at this point the Konrad discontinuity passes close to the surface.

It would be wrong to think that only basalts will be encountered below the Konrad discontinuity. If the idea of the Biarmiyan Range is correct, then here geologists and geophysicists will learn how layers similar in geophysical characteristics to the basaltic originate. These layers will or may be ordinary sedimentary rocks greatly compacted by repeated folding.

It may be assumed that the rocks of the Biarmiyan Range underwent no less than two major stages of folding, after which they became very dense and similar to basalts (in density, at least).

Well, and what if we find at these depths only rocks that solidified from a once molten fiery-liquid mass; what if the magmatists are right after all? Then too a definite cycle of regularities will be outlined. We will probably discover signs which will throw light on the laws of distribution of iron and copper ores, as well as those of a great variety of rare elements in this part of the Biarmiyan Range.

The discussion as to where to sink the Urals drill-hole is not yet over. Scientists have indicated many points. Each scientist wants to check his "own" hypothesis. One thing is clear: the hole must be sunk so as to give maximum advantage. The more questions it answers, the better. But all the problems cannot be solved with one hole anyway.

The Stone from the Kola Speaks

The second stone was given to me in the war years by one of my students, a poet called V. Zanadvorov who, unfortunately, was killed soon afterwards. Having graduated from prospecting technical school, Zanadvorov visited many parts of the country, among them the Kola Peninsula. Then he entered the Geology Department of the Perm State University.

Once Zanadvorov and I had a talk. He told me a great deal about his trips over the Kola Peninsula and other parts of the country, and recited his verses to me. I still remember some of them:

> I know not what dearer to me is,
> The Urals in childhood adored,
> The wild roadless tundra of Murmansk,
> Or the places I've never explored.

Before leaving for the front Zanadvorov brought back from the Murmansk tundra an ordinary piece of granite which seemed to have nothing remarkable about it. He gave it to me.

A small flesh-pink lump of rock with slightly lustrous crystals of feldspar, small inclusions of black mica and sections of quartz. I have it still in my collection, and it reminds me of Zanadvorov and tells me the very complicated story of its origin.

The runes of the Karelian epic *Kalevala* contain a curious legend describing the act of creation of the Earth and the sky. The legend says that before anything existed in the world a duck came flying and laid seven eggs, six of them of gold and the seventh of iron. It laid the eggs in the sea, into the lap of the mother goddess of water. The goddess threw the eggs into the water and they broke. But the eggs did not perish in the sea ooze:

> From an egg, its lower portion,
>   Mother Earth came into being;
> From an egg, its upper portion,
>   The heavens issued skyward soaring;
> From a yolk, its upper portion,

Fiery rose the Sun in splendour;
From a white, its upper portion,
Came the pale moon gleaming nightly;
From an egg, its speckled portion,
Scattered stars into the heavens;
From an egg, its darker portion,
In the air the storm clouds gathered.

But the granite tells us a different story of its origin.

Here is how the magmatists translate its story. Granite and many other rocks of the Kola Peninsula came from a fiery-liquid mass called magma which broke through from beneath the Earth's crust. There were very many faults through which the magma issued or intruded into the crust, and they occurred at different times. For example, Academician Fersman who studied the rocks of the Lovozero tundra said that they came here through faults that the Umba and Lovozero lakes now fill.

For a long time Fersman's idea was considered beyond dispute. Various economic minerals are associated with the rocks studied in the Khibiny Mountains, primarily the mineral apatite. This mineral is processed into superphosphate which is used as a fertilizer. Many other useful minerals were found here together with apatite.

The transformist-neptunists draw a different picture. They consider that the most ancient rocks discovered here formed not less than three and a half thousand million years ago. There are a number of indications that they should be classed as sedimentary rocks. Only later did they change to granites. There are on display in the show cases of the museum of

the Kola Branch of the Academy of Sciences of the U.S.S.R. laminated granite gneisses, quartzites with marks of oscillation ripples and other signs confirming beyond doubt the sedimentary origin of many of the rocks of the Kola Peninsula that were previously considered to be of magmatic origin.

Even in the younger rocks in which Academician A. Y. Fersman found apatite, sections were found which contained plants that existed in the Lovozero tundra about two hundred and fifty million years ago. The magmatists hold that these plants and the rocks enclosing them were taken from the edge zones of the magmatic hearth. But the neoneptunist-transformists say that the rocks containing the plant remains are sections of unchanged primary rocks.

Who is right? Maybe what the *Kalevala* says is true:

> Then did lakes begin to tremble,
> Tow'ring copper mountains shuddered,
> Rocks titanic cracked asunder,
> Lofty cliffs did fall to pieces....

Maybe faulting actually did occur here, and magma issued out from the faults? Then a hole sunk in the faulting zone will reveal mainly a monotonous complex of rocks throughout the entire thickness of the Earth's crust.

True, some people think that very ancient primary rocks will be encountered in the mantle zone, their age being five or six, rather than three and a half, thousand million years.

But if the transformists are right, then beneath the apatite-bearing rocks we shall find absolutely unchanged layers. Maybe they are

underlain by Cambrian sediments of the same kind as at the village of Markovo on the Lena? If this is so, there may be accumulations of petroleum under the apatite-containing rocks.

For a long time this seemed rather improbable.

But once in December 1951 a mine foreman working in an apatite mine heard a strange kind of whistling noise coming from under the ground. Two workers came up to him. "That's underground gas," said one of the newcomers. "Let's see if it burns." He struck a match and there was an explosion. The foreman and the workers got off with severe burns, but they might have forfeited their lives.

The incident was forgotten. And only after it was repeated in 1954 did the workers of the Kola Branch of the U.S.S.R. Academy of Sciences take an interest in it.

By 1963 I. A. Petersilye, a research worker at the Branch, had established that the complex of Khibiny magmatic rocks included a large amount not only of petroleum gases, but of dispersed solid and liquid bitumens as well. Their quantity is as large as that in a large oil field. The only difference is that in conventional sedimentary oil deposits the gas and oil are enclosed in the pores of the rock, whereas here they are concentrated in crystals. There are especially large amounts of gas and petroleum in the minerals which contain aluminium. Oil experts have calculated that they contain over 230 cubic centimetres of gas per kilogram of rock. And how much gas would a ton, a million, or a thousand million tons of rock contain?

In special laboratories at the Kola Branch the same petroleum gases were obtained artificially at temperatures of 1,200°C. This seems to confirm the relationship between the petroleum gases and magmatic rocks.

This again led to controversy. The adherents of the magma hypothesis triumphed. At last gas and petroleum had been discovered in typically magmatic rocks! Hence, the economics of the Kola Peninsula, which had always been short of mineral fuels, could be changed sharply. Now the enthusiasts of Polar regions would have their own petroleum and gas. We must start drilling!

The Kola Peninsula needs deep and superdeep holes. Of course, one of them must be sunk in the vicinity of the town of Kirovsk in the Khibiny Mountains. Petroleum experts say that gas is the breath of oil. And what if rocks are found under Kirovsk, from which both gas and petroleum can be extracted?

But the discussion is not over yet. Sceptics assert that it is impossible to find rocks on the Kola Peninsula from which oil can be extracted. They suggest drilling the hole in one of the remotest north-western points of the country, at the Pechenga copper and nickel deposit. There, the geologists say, the basaltic layer comes close to the Earth's surface, and many ore deposits may be connected with that layer.

Who is right, the oil men or the ore men? Whose viewpoint will win? Maybe not one, but several holes should be sunk on the Kola Peninsula?

The Story of the Third and Fourth Stones

These stones, the third and the fourth, lie next to each other in my collection. One of them is white, the other black.

The white opaque stone is kept in a fused flask because it is attacked by atmospheric moisture. This is rock salt which was brought to me from the neighbourhood of the town of Guryev in the Caspian lowlands, from the lowest reaches of the Ural and Emba rivers.

I found the black stone during a trip to the Baku oil fields. It comes from a place not far from the fire worshippers' temple in Surakhany.

Both these stones are connected with petroleum. The rock salt was taken near one of the oil deposits. I picked up the black stone in the region of an oil field too. It is known as kir, solidified weathered petroleum mixed with dirt.

If you examine closely the pieces of rock salt and kir you can find traces of the past in them, telling of how they originated.

On windless days on the surface of present-day salt lakes, such as Elton or Baskunchak, you can sometimes see strange pyramid boats floating, made up of tiny crystallized cubes of rock salt. When there are even small waves these pyramid boats are swept over by the water, which fills their hollow part and sinks them. These boats are what seams of rock salt are made of. In my stone, taken from a salt plug which broke through to the surface from a great depth, the characteristic pattern of these pyramids

can be clearly distinguished, testifying to the sedimentary origin of the salt.

The salt seams accumulated here were at first covered by a layer of sediments more than seven thousand metres thick. Under their weight the salt began to flow and was pressed out into the zone of least resistance, neither downwards, nor sideways, but upwards. When salt flows like this its multicoloured seams are especially beautiful. For instance, the initial stage of flow of salt can be seen in the Solikamsk mines, where it is crumpled into quaint curves resembling frozen waves.

Here, in the Caspian lowlands for the salt to break through to the surface it had to pierce and partially lift an immense layer of sedimentary rocks. Such salt pillars or plugs which have forced their way upwards are sometimes as much as one and a half or two kilimetres in diameter or even larger. In shape they resemble a drop with its wide end facing upwards. The deformed layers lifted by the salt often hold accumulations of petroleum.

In Iraq there are some salt pillar-plugs that are still moving upwards. From an aeroplane you get the impression of glaciers spreading over the ground. Actually these are masses of white salt flowing along the surface.

What is there in common between the white and the black stones?

Their paths, which lead from the depths of the Earth. The black stone—solidified petroleum—also broke out of the depths, but with mud instead of salt.

There are many mud volcanoes in the neigh-

bourhood of the Apsheron Peninsula. One of them, Lok-Batan by name, is located within the limits of the city of Baku, in its outskirts.

Academician Gubkin was the first to prove the industrial value of mud volcanoes. He suggested drilling their marginal deposits, and the very first hole in the district of Lok-Batan gave a gushing outburst of petroleum.

A very large number of mud volcanoes are concealed beneath the Caspian Sea. A major eruption of a mud volcano occurred on December 4, 1950 in the district of what is known as the Kumani Bank. In the night a spout of gas burst out from the bottom of the sea and caught fire. The flame was up to 100 metres high, and its glow could be seen in Baku. The volcano began to throw up mud together with the petroleum. There was so much of it that it formed an island about a kilometre long, more than 500 metres wide and up to six metres high above the surface of the water. But the island did not adorn the sea for very long: the first storm washed it away to the last grain.

Now all mud volcano zones are drilled, and large accumulations of petroleum are found there.

And so it turns out that white and black are often akin. The mud, however, burst out through a narrow channel, and not in a wide pillar like the salt. In Surakhany petroleum gas broke through to the surface together with the mud. Just over 100 years ago there was still a fire worshippers' temple here. The priests of the god Ormuzda laid pipes through to the pediment of this temple, and through them

came a stream of petroleum gas. The gas gave a never-dying flame, and caused great awe among believers!

Afterwards, when it was established that the burning fountain of gas was due to petroleum, the fire worshippers were asked to continue their activities elsewhere. One of the first oil wells was sunk here, and during the many scores of years that the Surakhany oil field has been in existence, even before the October Revolution, many millions of tons of petroleum have been extracted here. At that time the Surakhany pool was considered one of the largest in the world.

That is why super-deep holes are being planned in the zones where the white and black stones were found. If there is petroleum at a depth of three to five kilometres, why should there not be some at a depth of 15 to 18 kilometres as well? Maybe here we will finally find the answer to the question of the further trends of oil drilling. Perhaps petroleum of organic origin is but a small fraction of the world's reserves of petroleum, which have remained untouched up till now.

But even if we do not find oil at that depth, geologists will say: "Negative results are a positive result." It only means that afterwards we shall not drill again for oil at such depths and will thus save a lot of money.

The Caucasus has long been famous not only for its oil, but for large reserves of various metallic minerals as well.

A legend has come down to us about how the Ossetian Prince Os-Bagatar sought the

hand of the Georgian Princess Tamara. According to the custom brides had to be paid for, and Os-Bagatar, who lived near what is now the Ossetian Military Road, offered as much silver as a laden ass could carry away, which was quite a price for those times. The precious metal could be mined only near what is now the Sadon lead-zinc deposit. Os-Bagatar mined silver until his death. But after he died mining of the precious metal was almost entirely discontinued. Not that there was nobody to buy brides for, of course. Probably the section that contained the greatest accumulation of the metal was exhausted. But this does not mean that there are not new, and perhaps larger accumulations in other districts, where the amount of silver is so great that not only one, but even a thousand laden asses could not carry it away.

The super-deep hole, intended to reveal whether economically useful ores may be distributed regularly in relation to magmatic rocks, must be located in places where the basaltic layer may come close to the surface. We know the place where such a hole could be sunk. Where the River Arax separates the Milskaya and Muganskaya steppes, about 100 or 150 kilometres from where the Arax falls into the Kura, there is a small village called Karadonly. This is the point where what geologists call the basaltic layer comes closest to the surface in the whole of the Caucasus. Whether it is really the basaltic layer or the same as we assume in the Urals, we do not know as yet. We can only put forward hypotheses. The hole sunk here will have a

sufficient supply of water, which is always necessary in drilling. The place is easily supplied with electricity. Thus, Karadonly has every right to become the site for drilling a super-deep hole.

There are many prospects. Which will be chosen—petroleum or ore—is still a question of the future. But of the near future!

A Message from the Fifth Stone

This stone is not in my collection yet, but I know what it should look like.

Here are its distinctive features. Colour—grey, dark grey or black. It should be rough to the touch. Under a powerful lens tiny inclusions of olivine, a bottle-green mineral, should be visible. Under the microscope it will be seen distinctly that the minute crystals constituting the rock are in complete disorder. This is basalt, the substance which constitutes the basaltic layer of the Earth.

Of course, it is no great feat to obtain this rock. They have it in any museum, or in any geological establishment. But what I need is not just any kind of basalt, but basalt brought up from a super-deep hole sunk on the Kuril Islands.

So far I have several basalt specimens in my collection, obtained from various parts of the country. They come from the right bank of the Yenisei, from holes drilled at many points of the European part of the U.S.S.R., and from the Urals. And each of them is individual.

Each of them has its own personality, character and fate.

Especially interesting are certain rocks from the Urals, which greatly resemble basalt in appearance. But under the microscope they reveal specific intrinsic features. Traces of microscopic organic remains can easily be discerned in them. Traces of life in basalt which melts at a temperature above 1,000 degrees!

At such a temperature any traces of life in the rock would disappear completely. Remelting of the rock would change its character completely. But here we distinctly see such traces. And micropaleontologists, men who study the microscopic remains of life of far-off geological epochs, have proved them to exist in this rock.

Here the magmatic theory of rock formation is helpless. It is quite evident that these rocks could not have originated from a melt ejected from the neck of a volcano. This is a case of complex geological processes, primarily, recrystallization of sedimentary rocks giving them the appearance of basalt. This means that the rock underwent such complex changes during its lifetime that it came to resemble volcanic rock, but at the same time retained traces of its former life.

The life history of this rock can be pictured roughly as follows: first it was deposited at the bottom of the sea and was ordinary sea ooze in which the remains of shelled microorganisms accumulated. The shells were calcareous, like those of most organisms of this kind. Then the ooze was compressed into a compact clayey rock. Later, under the action of circulating

solutions minute crystals began to crystallize out in it. It is not impossible that this process took place under high pressure. Maybe the rock was compressed by the weight of a layer of ocean water many kilometres thick, or maybe it sank into the depths of the Earth's crust. But the fact is that under the combined action of pressure, a certain rise in temperature and solutions circulating through the rock, the minute crystals characteristic of basalt began to form and arrange themselves in complete disorder. And the rock began to resemble basalt.

It still seems strange that we could make such a mistake, when studying the regions of the eastern slopes of the Urals, as to class positively all the basalts as volcanic rocks. We say that volcanic activity occurred everywhere in this area in the past, basing our conclusions on the data of the method of analogies, the method of actualism.

So this method has failed us once more? It seems so. In a number of cases we have been too certain of its infallibility, but detailed investigations oblige us to make certain corrections in our habitual views. That is why I am waiting impatiently for the moment when I shall be able to add basalt from the Kuril Islands to my collection. Of course, I shall have it studied under the microscope too. It will be interesting to see a piece of rock from the basaltic layer of the Pacific Ocean. It is not impossible that this basalt which I will finally add to my collection will differ greatly from the Urals basalt in inner features. Perhaps the volcanists are right in some cases, while other

cases confirm the views of the neoneptunist-transformists who contend that certain rocks of volcanic appearance may be of non-volcanic origin.

This will probably be the end of the two-hundred-years' discussion on basalts. The common features of basalts of igneous and of other origin will be found.

But what will the Kuril hole yield if we again slip into the realm of realistic science fiction? What will be discovered in the depths of the Earth beneath the basaltic layer?

If the basalts here actually originated by discharge from underground hearths we may encounter either freezing or active volcanic foci. Then the volcanists will be able to declare triumphantly: just such a fiery-liquid mass must exist beneath the Earth's crust! But will they be right? I don't think so.

Of course, one hole, no matter how deep it is, cannot solve all the extremely complicated problems connected with the geological structure of the inner zones of the Earth.

Whatever the result we get from drilling a super-deep hole on the Kuril Islands, we shall still not be able to decide what we are likely to encounter in any other part of the zone beneath the Earth's crust. There is therefore a definite purpose behind the decision to drill five holes at five different points of the U.S.S.R.

Courtiers of the "Queen of the Depths"

"Queen of the Depths" is the name given to petroleum, because the wells that have to be sunk to extract it are the deepest. Not a single mineral is won from such a depth. And it is quite natural that those whose job it is to prospect for and extract petroleum have been dubbed unofficially the "courtiers" of the "Queen of the Depths". Oil workers are the men with the greatest experience in penetrating into the depths of the Earth, experience invaluable to the development of projects of super-deep drill-holes.

The depth that has now been reached was not achieved all at once. I remember how at the same XVII International Congress in 1937 the fact that "Gulf Production" of America had sunk a well three thousand metres deep was mentioned as a great accomplishment. I remember the record before that, a well sunk by "Rosenkratz Field" in California to a depth of 2,227 metres, while still earlier, at the turn of the century, the deepest wells were 350 to 400 metres. In 1958 "Philips Petroleum" drilled a well in western Texas 7,724 metres deep. This is still the record, but an eight kilometre well is under way now in southern Louisiana.

We are not out to break records. All deep wells drilled to prospect for or extract petroleum are planned to a depth of two, three, four or five thousand metres below the surface. The depth of these wells depends on the district where the petroleum occurs. For instance, in Bashkiria and Tataria there is hardly any need

to sink wells any deeper than one and a half or two thousand metres, because the sedimentary cover reaches down only to that depth. In some parts of the Pre-Urals, true, it is observed at greater depths. One of the wells in the vicinity of Krasnokamsk was sunk to 2,900 metres from the surface, which is the limit of the sedimentary cover at this point, but no petroleum was found. According to I. M. Gubkin's hypothesis there was no sense in drilling any deeper.

And what about the Caucasus? Wells as deep as five kilometres are sunk not only on the continent near Baku, but in the Caspian as well, in the neighbourhood of the Apsheron Peninsula, because here the sedimentary cover goes down to such depths and even further, and it contains oil everywhere. Hence, it is expedient to drill deep wells in this region.

Well depths are not selected at random. Drilling of industrial wells for prospecting, exploration and extraction is preceded by a great deal of preparatory work. It involves drilling structural key holes. Each of them is planned on the basis of a complex programme of preliminary geophysical investigations.

Drilling often takes years, and everything the boring tubes encounter is brought out on to the surface. This is very laborious work. Pipes are screwed together to make a column and a certain number of metres is drilled. Then to get the core—the column of rock that enters the boring tube—the entire composite pipe is raised to the surface.

When drilling is carried out only to a small depth this can be tolerated. But when the depths

to be investigated run into thousands of metres, such a method of drilling—unscrewing the pipes to get out a few metres of core and then screwing them together again—is very hard work. But it is justified.

Everything taken out of the drill-hole is investigated in minute detail. Geologists of all tenors study the rock in order to give recommendations to future investigators, as to what they will encounter at these depths when drilling new holes at some distance from the key hole.

But this does not exhaust the investigation. When the hole has been sunk it is studied by geophysicists to get more detailed information on all the various physical properties of the rocks: their magnetic and electric properties, gravity and radioactivity. All this is done in order to be able to decipher signals coming from the depths correctly in another place, when using the same methods.

In the U.S.A. such structural key holes were drilled over considerable areas in checkerboard fashion, approximately 25 km apart. In the U.S.S.R. there are state networks of structural holes in parts of the Volga-Urals oil-bearing region and in many other areas of the European part of the U.S.S.R. Some holes have been drilled in Western Siberia, in the new industrial oil-bearing districts, but large areas are still without a network of structural key holes.

Many surprises lay in store for the drillers. There was a newspaper report in 1960 describing an event that may be regarded as routine work for the driller. An industrial well was being

drilled offshore south of Baku. The driller Gasanov and his helper Babayev were preparing to raise the regular portion of core. They were to extract an eight-metre column of rock and lay it in a box.

But suddenly a rumbling was heard. The sea started to bubble. An immense fountain of mud rose above the surface with a roar to about the height of a ten-storey building. Emergency! The hole had struck the neck of a mud volcano in the depths. The outpour of mud had to be stopped as quickly as possible to save the rig from being destroyed. A heavy clay slurry was pumped down the well. The idea was that the slurry would stop the flow of mud, but at first it did not help. The drillers kept trying different measures to stop the powerful rush of mud and gas from the depths.

At last the mud volcano was conquered. But the gas accompanying the mud found an exit. Powerful streams of gas began to break out on to the surface. The whole foundation of the well began to tremble. But drillers know what to do in such cases, too. Their emergency gear had been prepared beforehand. The gas flow was finally stopped. And only when it suddenly grew still did the drillers realize that their fight with the underground elements had been going on for over two shifts....

I repeat that this was a routine case; drillers often have to cope with such emergencies, and sometimes even more complicated ones. The "queen of the depths" is capricious. And her "courtiers" do all kinds of ingenious things to please her in the long run.

But all this has to do with present-day drilling techniques and practices. What about the future super-deep drilling—will we still have to raise all the pipes every few metres and let them down again?

No, a different mode of drilling will be used then. As far back as the twenties of this century the talented engineer M. A. Kapelyushnikov invented what is known as the turbodrill. Essentially this invention consists in the fact that the pipe column lowered into the well does not rotate. It serves only to feed the cutting tool of the turbine machine downwards, and the only part that rotates is the turbine head. The latter is actuated either by water or by the clay slurry pumped into the hole. This slurry not only actuates the turbine, but also cements, and argillizes the well walls to keep them from caving in.

Kapelyushnikov's turbodrill has now been greatly perfected and elaborated. There has also appeared a sister to the turbodrill, the electrodrill, in which the cutting tool is actuated by electricity, but the working principle remains the same; only the cutting tool rotates.

A long time ago, before Kapelyushnikov, a method was invented by which wells could be drilled without bringing the rock column (core) up to the surface. In this method the rock is all crushed at the bottom of the hole by means of special bits, after which it is washed up to the surface with water or a clay slurry. This greatly accelerates drilling. However, the problem of raising and lowering operations during super-deep drilling has not yet been completely

solved. Possibly, the turbodrill or electrodrill will be lowered and raised with special ropes rather than pipes. They will have to be strong and light, because at such a depth the weight of the ropes themselves will be critical. Many hundreds of metres of holes are now drilled each month by extending pipe columns rather than raising and lowering them innumerable times.

One of the questions drill men are especially interested in is that of cutting tools. When the U.S.S.R. was short of diamonds, drill heads were equipped with cutters made of special steels. Such alloys as pobedite were developed, which had a comparatively long service life, but even these did not satisfy the drillers.

Man's dream of an "eternal" hammering and cutting tool is reflected in many tales and legends. We may quote the Scandinavian Volsunga Saga.

According to the legend, the god Odin decides to present the mightiest hero with a sword which would easily cut and crush anything. Odin appears before the people and thrusts the sword into an oak, saying it will belong to anyone who can pull it out again. Sieggeir, king of Goutland says he can do it, but his efforts are in vain. Then up to the oak comes the hero Sigmund and easily withdraws the sword. Sieggeir asks Sigmund to sell him the sword, but Sigmund only laughs and says: "You could have had it for nothing. But as I withdrew it I shall keep it."

Sieggeir nurses a grudge against Sigmund, and cunningly lures him and his foster son Sinfiotli into his kingdom, where he falls on

them unexpectedly and takes them prisoner. He takes Sigmund's sword away from him and devises a terrible execution for the hero. The king orders a ditch to be dug and separated into two halves with a thick slab of granite. He throws Sigmund into one half and Sinfiotli into the other. At the last moment Sigmund's sister, who is Sieggeir's wife, succeeds in giving the magic sword to Sinfiotli in a sheaf of barley. The ditch is filled with earth and covered with boulders. A great hill is formed at the place. When the people have left, Sinfiotli touches the sheaf and feels the sword hilt there. He takes the sword and thrusts it easily through the granite slab. Sigmund and Sinfiotli saw through the granite slab, then hack their way through the earth and boulders right out on to the surface... Just as in a fairy-tale!

We still have no cutting tools as hard as Sigmund's sword. The hardest of all known substances is diamond. True, just recently the Americans developed a material called borazon, a boron nitride which cuts diamond. But even it does not satisfy drillers. Scientists all over the world are racking their brains to invent superhard alloys, but so far there is nothing harder than diamond and borazon. Perhaps quantum light generators, something like those described by A. Tolstoi in his *Garin Death Ray* will come to the driller's aid. Using a mirror, Garin succeeded in focussing light rays into a fine pencil, which cut through anything that happened to be in its way.

Scientists have put Tolstoi's idea into practice. It was found that a mirror would not do

for this purpose, and the power source is a different one, immeasurably more powerful. On the basis of quantum mechanics a generator has been created with which the energy of a light flux can be focussed into a pencil so concentrated that it actually does cut through anything in its way. Such a ray will cut a hole in steel in thousandths of a second, will cut diamond or heat a rock to 8,000 degrees. These instruments, called lasers and masers, are constantly being improved. And who knows, maybe in the near future they will become the principal element in cutting tools. But so far no drilling rigs of this kind have been invented.

Meanwhile, the science of drilling keeps bringing up more and more problems that have to be solved. It is supposed that drilling will have to be carried out at immense pressures and high temperatures. Drilling equipment will have to be made of superstrong, but also superlight materials.

Maybe research workers will decide against the use of metallic structures in this case, in favour of plastics. These synthetic substitutes are being used more and more extensively in industry and in the home. It is difficult to foresee what developments will be made. We must delve deeper and deeper into the depths, and this brings up very many other questions. How to run the power down to such depths? What will be better for this purpose—the turbodrill or the electrodrill? Even the weight of a present-day electric cable running down to a depth of 15 kilometres will be so great that the cable will break under its own weight!....

The water that will have to be pumped down there will presumably turn into steam with a temperature of 400-450 degrees. Perhaps some kind of cooling system will be necessary? Even at the depths where water can still exist as such it will corrode the pump valves. Of course, new materials may be of help, but would it not be simpler to use compressed air instead of water?

There is an incredibly large number of such questions. The design of a new drilling unit that will be able to go down to a great depth and cut into the mantle of the Earth requires the solution of an ever increasing number of new engineering problems.

And how is the rock to be extracted from such a depth? It will most likely be necessary to develop new drilling practices. Obviously, a great deal of attention will have to be devoted to devices which are capable of giving readings without the core or solution being hoisted to the surface. Maybe only small samples will be taken as a check at definite depths. The first, say, five kilometres are drilled crushing the rock to a slurry, and after that a piece of core is taken out. Then another three or four kilometres are run without raising any rock. As to the sections drilled without removing cores, they will be carefully investigated by geophysical methods.

And the instruments with which this is done will have to be redesigned too. They will have to be clad in housings that can withstand pressure and high temperatures. These instruments of the future are already being designed. And the day is not far off when we shall start super-

deep drilling. The newspapers report that rigs are already being constructed that will be able to drill holes up to 10 kilometres deep. The first of these holes will be an experimental one, and will be drilled in the Caspian lowlands. Much of what we have just been discussing has been taken into account in this highly perfected drilling unit.

An Artificial Mantle

Do many of the passengers on the Moscow Underground take the trouble to examine attentively the walls of its splendid stations? It is mainly the architecture and general appearance of the halls that is admired. But it is worth while having a good look at the walls.

Take, for instance, the marble facing on the walls of Dzerzhinskaya Station. Not everyone can say what it looks like.

If we examine the marble slabs of this station closely, we can read in them some interesting pages from the history of the Earth. In their time, during the formation of the marble, the organic inclusions contained in the ancient ooze were dragged into its various layers and microlayers. Now they stand out as grey parallel lines twisted into delicate zigzags. These zigzags are especially effective in Baltiyskaya Station on the Leningrad Underground. It hardly occurs to anyone that these are stone chronicles recording dramatic episodes in the life of the marble, connected with so-called plastic deformations that occurred under stresses of four thousand kilograms per square centimetre.

Still more interesting are experiments that have been conducted with Ural pyritic ore. In mines and some of the pits where this ore is extracted, especially at the Karabash deposit in the southern Urals, the sheet-like bodies it is composed of can be seen to wind and meander in fantastic patterns.

The experiments showed that copper ore can also be made to flow, but this requires pressures of 10 or 12 thousand kilograms per square centimetre. Thus, by comparing the results of the processes occurring in nature with experimental data we come to the brink of knowing the processes which take place in the Earth's mantle.

Practically speaking, we can obtain an artificial mantle in the laboratory. To do this we have to reproduce the conditions that must exist beneath the Earth's crust. The first of them is the pressure. It is immense. Three elephants balanced on the nail of a forefinger! But such pressures are quite attainable with modern laboratory equipment. The value is not difficult to calculate, and therefore we can tell at exactly what pressure the rocks at any particular depth below the surface of the ground or the ocean are compressed.

The temperature of the mantle is a more difficult question. Scientists do not agree as to the extent and nature of change of the temperature as we move towards the centre of the Earth.

Another factor that must be taken into account are the waters that penetrate the rocks. The action of water under pressure is different

from that at the Earth's surface. Each pore, no matter how minute it is, even microscopic, will imbibe the moisture, and the rock itself will also have different properties under such conditions. Possibly, this is the reason for the radical difference between the oceanic parts of the Earth's crust and its continental parts. Maybe the properties of rocks change so pronouncedly under the pressure of the water penetrating into their pores that sedimentary rocks and granites acquire properties very close to those of basalts. Is it not because of this that the basaltic layer lies so close to the surface in the region of the ocean floor? And maybe it is not a basaltic layer at all, but a sedimentary or granitic one metamorphozed beyond recognition?

The consequence of pressure, temperature, and the porosity and permeability of rocks is, as we have seen, their plasticity, elasticity and toughness. We can obtain all this in special laboratories where the behaviour of rocks under immense pressures and high temperatures is studied.

In one of his reports Prof. L. F. Vereshchagin, Director of the Laboratory of the Physics of Very High Pressures of the U.S.S.R. Academy of Sciences stated that when various materials were subjected to high pressures their original properties were found to change. For instance, cast iron, rock salt and marble placed in a liquid compressed to 20 or 25 thousand atmospheres *underwent surprising changes. They became* plastic and acquired a kind of specific superstrength.

But when we attempt to reproduce the properties rocks must have under the conditions existent in the mantle, we come up against many difficulties. All the rocks in the mantle, even those that have been studied in great detail, are in a medium we know nothing about. And as to the role of this medium, we can judge it from experiments conducted with rock salt. It was found that rock salt begins to flow at comparatively low pressures. By subjecting it to a pressure of only 40-80 kilograms per square centimetre it can be pressed into a narrow crack in a steel plate.

But if the rock salt is heated just a little, say to 200 or 300 degrees, it can be pressed through the same crack under a pressure only half that in the previous test.

Still more striking is the effect obtained if the crack in the steel plate is lined with fused gypsum or fused salt. Now the rock salt can be pressed into the crack with a pressure of only two or three kilograms per square centimetre, that is, the stress required is 10 to 15 times smaller still.

But the geological observations of the behaviour of marble and quartzite contradict these laboratory tests. In nature quartzite undergoes plastic deformations more readily than marble, while in the laboratory a smaller stress is required to cause plastic deformation in marble.

A riddle? Yes, so far. And there are thousands more of them. Research workers are constantly confronted with the necessity of solving equations with many unknowns. But we must not despair. Man has just built himself a powerful

assistant, the electronic computer, and it is already working hard for the geologists, helping to solve problems that were formerly completely insoluble.

Computers enable us to take into account with maximum accuracy all the processes occurring in the Earth's crust or mantle.

We shall be able to calculate practically what the Earth's mantle looks like. The results of calculating the strength, density and elasticity of the rocks will determine the choice of technical equipment as well as the design of the drilling units.

The calculating machine will help to find the answer to the question of the metals or artificial plastics needed to construct the drill pipes. The machine will tell us that we shall have to create certain kinds of rocks to reinforce the walls of the holes. Perhaps they will be the metamorphozed rocks through which the drill hole passes. Or possibly we shall have to develop an electrochemical method of reinforcing the walls of the hole. Calculated data will also give the answer to the problem of the hole diameter.

In the neighbourhood of the town of Totma I saw a well with casing pipes that dated back to the 15th century. The initial diameter of the well was 60 centimetres, and at the bottom, 250 metres below the surface, it narrowed to 30 centimetres. The well was encased with pipes made of strong hollow tree trunks wrapped in pitch-impregnated canvas. It was a technical wonder for those times.

The hole designs we use at present are of essentially the same type.

Calculations show that the initial diameter of a super-deep hole may be about two metres. Such a hole would narrow to 13 or 15 centimetres at a depth of 15 to 18 kilometres. Computers will calculate the strength of the equipment. In order to tell how pipes made of a ferro-titanium alloy or any other metal will behave in the depths, and to find out how they will stretch and contract when the drilling stem is raised or lowered, tens, hundreds and maybe thousands of different kinds of problems have to be solved. The solutions will differ depending on how we imagine the conditions that will be encountered under the Earth's crust.

Modern science enables us to make allowance for all these conditions, and we shall not have to grope blindly when drilling super-deep wells. We shall enter the bowels of the Earth armed with all the achievements of engineering; we shall enter them as conquerors of the elements which not so long ago were considered mysterious and untamable.

And Here, Too, Synthesis

As we know, the various branches of science are becoming more and more differentiated. New branches and new trends keep appearing all the time. Over 120 new branches have appeared within geology alone, and the process is still going on. It is already impossible to be a specialist in geology in general. There are so many different trends that each geologist, practically speaking, becomes a narrow specialist

in some single field. But the opposite process also takes place, and it is no wonder that many new branches of science are born at the junction between two or three older ones.

What is to be done about drilling super-deep holes? Thousands of problems of all kinds arise that just cannot be solved by narrow specialists. There is no need to prove that hundreds of people of different specialities will be working on each of these holes. The ideas and dreams of different scientists will be focussed here. The hole will unite the interests of representatives of professions that at first glance seem to have nothing in common. Of course, it is impossible yet to describe the entire synthesis of sciences that will be brought about by each super-deep hole. Many books are still to be written about this, but some of the trends are already in sight.

Here is the picture as I imagine it. A piece of rock is extracted from a depth of 10 or 12 kilometres, say, from the hole on the Kola Peninsula. It will immediately be divided primarily among petrographers, men who study and describe rocks, geochemists, who reveal the conditions under which the rocks originated, and mineralogists, who describe and determine the minerals which make up the rocks.

Suppose the petrographers, mineralogists and geochemists say that the rock we raise from that depth is called eclogite. It will be indicated in the description that such rocks form, as a rule, either at very great depths, or under conditions of very high temperatures. Eclogites, the mineralogists will add, are rather well crystallized

rocks in which bright red garnet crystals contrast with green pyroxenes, and sometimes contain light or dark blue disthen interspersed among them.

There are many hypotheses as to the structure of the inner zones of the Earth. According to one of them the mineral olivine should be widespread in the depths, having formed when the rocks became impoverished in silica. Some scientists hold that there is a whole olivine belt under the Earth's crust (remember *The Garin Death Ray*, the geology of which was prompted entirely by Academician Fersman).

Others state that under high pressures basalts turn into eclogites. The higher the pressure, the larger the crystals.

Very many problems which are as yet far from clear are connected with eclogites. We sometimes find diamonds in the same places as this interesting rock. Specialists in economic minerals will therefore take part in the study of the eclogites.

Academician V. Sobolev tells that in two cases not only pieces of granite and pyroxenes were found in the eclogites of South Africa and Yakutia, but diamond crystals as well. They were discovered in ancient volcanic pipes. According to the magmatists this is proof that diamond-bearing rocks are products of high temperatures and very high pressures. For this reason research workers studying the synthesis of substances will also make their contributions to the investigation of the rock.

It is known that artificial diamonds are made at a pressure of about one hundred thousand

atmospheres and at temperatures of two or three thousand degrees. Almost all investigators consider that diamonds are products of the Earth's mantle, where this set of conditions exists in nature. Here the controversy about the origin of the rock under study will pass over to the tectonists studying the structure of the Earth and the Earth's crust.

Some well-known scientists, I. I. Krasnov, P. Y. Offman and V. V. Alexeyev, who studied the geological structure of diamond-bearing zones in Siberia, came to the conclusion that diamond deposits are related to the faulting zones of the Earth's crust. Such zones, Alexeyev points out, stretch over very great distances. They are consistent, and straight, and repeated revivals of volcanic activity are connected with them.

But not all the questions have been worked out clearly enough. At the All-Union Tectonic Conference in February, 1963, the geologist D. I. Musatov gave a report on the problems connected with the movement of magma along deep-seated faults from hearths located at a depth of 70-100 kilometres. He was obliged to admit that it was practically impossible for faults to remain in the form of open cracks for even a short space of time, because under the pressure of a rock column 70-100 kilometres high any open cracks would be tightly sealed. A similar phenomenon occurs in ice fields where even fairly wide leads disappear very quickly under the immense pressure.

Musatov said that the faults must be step-like in nature. He assumes that there might

be an arching effect here, so that individual blocks of the Earth's crust would maintain their cracks. And perhaps all this happened with the Earth as a whole expanding.

But this is all "maybe", and there is no evidence to substantiate it.

It is not by chance, therefore, that in considering the question of the origin of the volcanic pipes which contain diamonds, the transformists put forward an entirely different idea. They say that gigantic pressures are not at all obligatory, nor are high temperatures. Possibly, they say, diamond-bearing rocks are formed under ordinary or slightly elevated pressures. They are formed inside the Earth's crust as a result of the circulation of solutions which may introduce any chemical composition from various parts of the Earth's crust.

To solve the problem of the conditions under which eclogites and other diamond-bearing rocks form, specialists in thermodynamics will have to play their part in the investigation. They will attempt to establish the conditions for the formation of rocks under varying temperature, pressure, volume and concentration of different substances. Thermodynamics states that exact account must be taken of all the changes in these factors which are intimately related to one another. When the pressure changes, so does the temperature; if the temperature changes, the pressure must alter, etc.

There are minerals known to science that are indicators of definite temperatures. If we take the three different varieties of what is known as feldspar, we find that albite feldspar

melts at 1,100 degrees, while orthoclase melts at 1,770 degrees. The third variety of feldspar, anorthite, has a melting point of 1,550 degrees. This has been confirmed by experiment. There are many other such thermometer minerals, but we know that under different pressures the same albite, orthoclase and anorthite will have different melting points. Investigation of rocks taken from deep holes will help us to refine the calculations of thermodynamics.

But what do the rocks from different depths look like? There is a branch of science called structural geology. It develops practical methods of studying the forms of occurrence of rocks in the Earth's crust. It enables us to find out, for instance, whether the layers in question occur horizontally or at some angle to the horizon.

Anyone who has travelled along the Georgian Military Highway probably noticed that before entering the Daryal Canyon the road first passes through a zone where the Earth strata lie horizontally, and then these strata are inclined at a sharp angle of 70 and even 80 degrees. This indicates that at one time these rocks were upraised, and crumpled.

When sinking deep holes and mine shafts specialists in structural geology invariably establish that at first, in the uppermost zone, the rocks are fractured.

But if we go deeper, at a certain depth they pass into what is known as cleavage rocks which are outwardly monolithic. But when hit with a hammer they break up into thin sheets. Ordinary roofing slate is an example of cleavage rocks. Still deeper we encounter greatly twisted

rocks crumpled into small corrugations. It is thought that in the depths they acquire plasticity because of the temperature there, so that they are twisted into small corrugations even under only moderately high crumpling stresses. The next stage should be complete plasticity of the mass, and at a certain depth, perhaps, below the Earth's crust the rocks should pass into the molten state.

And now imagine again the columns of core being raised to the surface one after another. If our scheme is correct, we will obtain cracked rocks at first, then cleavage rocks, and finally corrugated ones. But if this regularity does not appear, specialists in the field of structural geology will have to start thinking up some new hypotheses.

Of course, research workers will also be interested in the age of the deep-seated rocks. Ordinary mica is especially valuable in this respect. The reason is that it contains potassium as one of its constituent elements, and potassium contains a certain amount of the unstable isotope (K-40).

This is a wonderful element; its lifetime is limited. Half of it decays completely in 1,300 million years, passing into an isotope of the inert gas argon (A-40). Specialists know how to separate this argon isotope from the mica and how to calculate the ratio of radioactive potassium and argon. From this it can be found how many years the rock containing the mica has existed.

The most likely figures that will be found here are 3,000 to 5,000 million years.

But what if other methods give values exceeding these figures by tens of times? Then philosophers, specialists in the field of geocosmogony, the science of the origin of the Earth, will begin to take part in the analysis.

A great many other trends could be mentioned, which will require the joint efforts of scientists for the investigation of the samples obtained when drilling super-deep holes. But the samples will not be the only object of investigation. Even the hole itself, the emptiness left after drilling, will be of very great interest to various types of geophysicists. Instruments will be lowered into the holes to verify, refine, and determine whether geophysicists have been correctly deciphering the signals we receive from the depths of the Earth.

So the paths of geologists, geophysicists, mathematicians, and geochemists—a great variety of specialists—will cross. The study of the data yielded by each of the holes will be a synthesis of numerous branches of science. And the result will be the discovery of new regularities, new knowledge, and new ways of conquering the depths of our planet.

The World
of Unsolved Riddles

Following in the Footsteps of the Classics

Once a friend of mine, a film producer, called on me.

"We need some unusual material for an interesting popular science film on how the Earth's depths are being conquered," he said. "The film must contain a thrilling plot, arguments, investigations—in a word, impact."

I found it difficult to answer right away, and said I would think it over.

The next morning I was at the library. I took down a volume of Jules Verne and started reading.

A group of scientists decided to descend into the depths of the Earth. They took advantage of the gigantic crater of an extinct volcano. Everywhere along their path they found cavities through which they descended farther and farther into the depths of the planet. Incredible things happened to them at every step. But the strangest thing was that inside the Earth the travellers found the temperature normal. An unusual point of view for the time the novel was written!

Jules Verne tells us about the age of the rocks encountered and the sequence of their bedding, holding that the most ancient, primordial rocks are very deep down. A great number of ore deposits are related to these primordial rocks. "In the schistose layers of magnificent green shades were iron and copper ores, and manganese ores with intercalations of platinum and gold," I read in the novel. And then, protesting against the investigation of the Earth with such a crude and insensitive tool as the drill, Jules Verne says that the bowels of our planet can be studied effectively only through cavities and cracks, the natural labyrinths of the Earth. He inhabits the underground world with long extinct monsters. The writer leads his travellers past fire-breathing volcanoes and their underground foci. The journey comes to a quite extraordinary end. The travellers float up on a raft on boiling water which afterwards gives way to red-hot lava.

Such geological ideas were quite natural for that time. As a matter of fact, no journey to the centre of the Earth occurred in Jules Verne's novel. The flow of boiling water threw the travellers out on the surface somewhere in the vicinity of the Stromboli volcano. They travelled a long way, from Iceland to Italy, missing the zone of the Earth's centre, and in fact Jules Verne did not describe what the depths of our planet are like.

V. A. Obruchev's *Plutonia* deals with the same problem. Doubtless, many episodes in his book were suggested by Jules Verne's novel. Obruchev also leads his characters through

cavities, but he describes our Earth as quite hollow inside and even puts a sun in the centre of the planet. Of course, Obruchev knew that the Earth cannot be hollow inside. It was just a trick the scientist used to describe the history of our planet's life.

As they pass deeper the characters of *Plutonia* meet more and more ancient specimens of extinct creatures. First the travellers came across some mammoths, then they saw one of the extinct predecessors of mammals, and then appeared the terrible giant lizards of the Mesozoic era.

The life of our brave investigators underground passed in fighting these creatures. They also studied the minerals they encountered, and found rich ore deposits. But all this was just a background for the story of the evolution of life, and Obruchev, like Jules Verne, did not show what the inside of the Earth is really like.

In one of their films Czech film producers took the path suggested by Obruchev. They showed fossil animals, bringing them to life again, and giving a vivid picture of the ancient world.

I recalled Conan Doyle's novel of a voyage to the centre of the Earth in a special apparatus resembling a deep-water bathyscaf, but here also the author went in mainly for sensations, catastrophes and unusual adventures. Nor did A. N. Tolstoi evade the theme of catastrophe in his *Garin Death Ray* which includes a story about the internal structure of the Earth.

But how to write a story so that not adventures, but scientific ideas themselves would be the sensational, or simply, the interesting part?

And I had a constantly recurring desire to telephone my producer-friend and say: "Nothing will come of it!"

Then I remembered a conversation I once had with an acquaintance of mine who is a psychologist. He told me: "Do you want to surprise your friends at a party? Write down four words beforehand on a slip of paper. First 'Pushkin', second 'chicken', third 'apple' and fourth 'nose'. Then ask your friends first to count to twenty and then quickly, without stopping to think, to name the best known poet, a domestic fowl, a fruit and a part of the face. Only rarely will anybody say anything else. Then take out the slip of paper and surprise everybody by showing them what you have written."

What the psychologist had told me was amusing. I should probably add a fifth question: what is there under the Earth's crust? I am certain that without thinking everybody would answer: magma! A molten fiery-liquid mass—magma.

We have already seen how popular the magmatic theory is, particularly among nonspecialists. It has been written about and shown in the cinema so often!

Several years ago I took part in making the film "The Story of a Stone". In this film the author of the screenplay M. S. Vitukhnovsky and the producer L. I. Rymarenko were able to bring the dead stone to life, and show it as

it develops. Vitukhnovsky in this case did away with the ideas of Jules Verne and Obruchev and followed the works of Academician A. Y. Fersman.

In classical works of art stone comes to life. It can convey a whole range of moods under the hands of a great sculptor or architect. But the greatest master of all is nature herself. The cameramen of the film were able to show the natural birth and death of stone.

Many people thought that the most impressive scenes were those of the life of magma, this raging fiery-liquid flame under the Earth's crust (the authors of the film were adherents of this theory).

On looking through the notes I had made during the filming of that picture, it occurred to me that in asking me to write a screenplay the people at the film studio probably expected a repetition of those scenes. They were all unconscious magmatists and quite confident that in the new screenplay I ought to show the same raging magma, volcanoes, eruptions, and the birth of rocks from fiery melts. That is, I ought to show what happens in the depths of the Earth according to the magmatists. But we know now that theirs is not the only point of view. Then maybe I should try to examine the material inside our planet from different standpoints, and clash the views of the magmatists and the neoneptunists? Yes, I decided that that was probably the only way to show up fully the complexity of the phenomena occurring in the depths of the planet.

And I got down to the screenplay.

If the Magmatists Are Right....

Intensive preparations were being made that day for The Opening of the Moho Frontier—that is what the newspapermen dubbed it. In the competition between two groups of drill men, Soviet and American, the victory had gone to the tenacity, endurance and courage of the scientists and engineers of the Soviet Union.

The world was at the brink of a sensational discovery. At last we would know what the Earth's crust conceals, what lies beneath it, what is beyond the Mohorovičić discontinuity.

On one of the Kuril Islands at some distance from the super-deep hole (it had just happened somehow that it was renamed Moho Island) a town of drillers had sprung up. Here, in the centre of an immense oval basin stood the engineering miracle, the derrick for the super-hole. Operations were supervised by a large number of specialists. At one side of the derrick stood the repair shop. It was just as unusual as everything else around the derrick. The strange thing was the silence, the absence of noise so characteristic of repair shops. Here most attention was devoted to inspection of the instruments serving the drilling operation. Their readings registered the penetration of the down-the-hole equipment into the Earth's crust to an accuracy of one centimetre.

All these instruments were connected to a loudspeaker which announced periodically how much had yet to be drilled to reach the Moho discontinuity. The metallic voice of the an-

nouncer which had been transmitted many times over the radio, now announced: "Twenty metres to go to the Moho frontier. Twenty metres! Twenty metres! Attention! Attention!"

Engineers had been hard at work developing methods of protecting the people from the catastrophes which might occur when the Moho frontier was opened. All the inhabitants had been evacuated from the town long ago. Even those who had remained until the last days near the drill-hole and in the repair shops had now been ordered to retreat to the mountain tops fringing the basin in which the derrick was situated.

The drilling apparatus was switched over to automatic control. Photo and cine cameras, periscopes, spectroscopes and a large number of other devices and instruments which were to register all the phenomena accompanying the moment when the Moho frontier opened were focussed on the drill-hole and the area round it from a special chamber resembling a pillbox.

At last the long awaited moment came. The announcer had just announced: "Five metres left to the opening of the Moho frontier... four metres... three metres... two...."

Everything was set in motion. It was impossible to see any details. Only the cine-film, which recorded these unique moments at a speed of about five hundred million frames per second, showed afterwards how the latticework of the derrick slowly (so it seemed on the screen) dissolved and vanished into thin air, and how a torrid whirlwind demolished all the structures surrounding the drill-hole.

Simultaneously, with a tremendous outburst of gases, a dazzling bright fiery column of magma flew upwards at an angle. Together with it came volcanic bombs, flung upwards to a tremendous height of several thousand metres!... A blood-red reflection coloured the whole neighbourhood, showing up the dark clouds of gas.

The din and rumbling grew in intensity. At first it was difficult to determine where the noise came from. Dull reports were heard, which grew louder and louder. They came from under the ground and were accompanied by gigantic fiery columns. The air shook with thunderclaps accompanied by sparkling streaks of lightning.

More and more electric discharges formed a dense network interlaced with the tops of the fiery columns. The whirlwind of flame stopped short of both the magma column and the ground, fanning out in mid-air. An unbearable smell of sulphur dioxide spread all around, making it difficult to breathe. Observers stationed several kilometres away were obliged to put on breathing apparatus.

The explosions continued, and the Earth trembled. A red hot stream began to fill the basin in which the drill-hole, the shops, and the houses had been situated. Before the eyes of the onlookers everything that an immense body of men had worked so hard on was demolished by the raging chaos.

A fiery column thrown out from under the Earth seemed like a wedge cutting into the whirling clouds of sulphurous gas and ashes. The darkness of the surroundings contrasted sharply with the hellish flame of raging magma.

The lake filled up further and further, and the fiery fountain gradually died down, covered with a mass of lava. The magma bubbled and splashed here and there. Caught up by a hurricane-like wind the lava turned into weird hair-like masses of rock. I remembered that on the Hawaiian Islands they were called "Pele's hair" after Pele, the goddess of volcanoes.

All this ended in a gigantic explosion. Once more a huge fiery column rushed upwards from the central part. The din and commotion was incredible. The Earth shuddered.

Then came silence, complete silence. It was difficult to believe that everything was over.

Gradually, slowly the ash began to settle on the ground. The finer particles continued to fall for many days. A hurricane scattered them almost all over the globe.

The sun shone again, only it seemed brighter now, and the clouds retained their blood-red tint for a long time, owing to the particles of subcrust substance carried off into the stratosphere.

Before us lay a lake of primordial substance. Mankind saw for the first time the mysterious substance that lies under the Earth's crust everywhere. Samples were taken immediately from various parts of the lava lake and sent to the laboratories of many countries. The whole world held its breath waiting for the results of the assays.

And here, the results have already been received at the coordination centre that headed all the super-deep drilling operations. The official report said that all the chemical elements

of the Mendeleyev Table had been discovered in the primordial substance! Their quantitative ratio was in almost complete agreement with calculated data. Some differences were noted compared to the average chemical composition of the rocks of the Earth's crust. Chemists found an increased content of heavy elements, with a predominance of those found in the Earth's crust in insignificant amounts. Curious data resulted, coinciding with what Academician Fersman had suggested, that is, with what had formed the basis of the hypothesis that the chemical composition of the Earth varied on approaching the centre.

The magmatists triumphed. The very fact that a fiery-liquid melt existed under the Earth's crust confirmed their ideas. The chemical composition of this primordial matter was still more convincing evidence. Now everybody was impatient to see what would happen when the magma cooled down. Would the laws of the development of the fiery-liquid mass be confirmed?

Scientists began to put forward suggestions as to what may be found in different parts of this lake of lava. By analogy with the Solovyova Gora deposit in the Urals, in the vicinity of Nizhny Tagil, it was expected that accumulations of platinum, chromite and other heavy elements would be found at the bottom of the lake. Those who studied this deposit say that it formed as a result of crystallization processes at an early stage of development of the magmatic hearth. Scientists related the formation of such deposits to the early fallout of refractory crystals from the magma and their deposition at the

bottom of the magmatic hearth. The platinum and chromite deposits of South Africa not far from the town of Bushveld, known as the Bushveld deposit, are of exactly the same origin.

Somebody suggested that something like the Canadian nickel deposit at Sudbury might be found near the bottom of the lava lake, where the settlement had formerly been situated. A large quantity of nickel minerals accumulated as deposits near the bottom at Sudbury. Scientists said that such deposits also formed during the first stage of the life of a magmatic hearth, when the substances in it separated according to their specific gravities.

Geologists began to single out sections on the map of the lava lake and give them names according to their supposed resemblance to what had been found when studying classical mineral deposits.

The northern district was called the Sudbury section. In the eastern part a Solovyova Gora was outlined, where an accumulation of platinum was expected. The southwestern section received the name of Kirunavara, after the Swedish iron ore deposit.

As far back as 1961 the Swedish geologist Per Gejer suggested that a part of the liquid magma melt enriched in iron, phosphorus and certain other elements had separated out. Later there was a discussion about the Kirunavara deposit. For instance, the geologist Lindergren suggested that the Kirunavara iron deposit was of primarily sedimentary origin. In his opinion the ores had afterwards metamorphozed. In their time many neoneptunist-transformists stated,

in agreement with Lindergren's views, that there were no, or almost no magmatic deposits at all. But now Per Gejer's hypothesis was widely propagated in the press. A great many papers on this subject appeared in special geological periodicals.

The central part of the lava lake came to be called the Kimberly section. Here, in the zone of the final gigantic explosion, an accumulation of diamonds was expected, similar to that in the famous Kimberly deposit in South Africa. The scientists expected to discover a diamond-bearing volcanic pipe.

Many months passed before the hot mass cooled down enough for the scientists to start studying it. It goes without saying that all the predictions were fully confirmed! The ideas put forward by the magmatists on the basis of investigations of the Kirunavara, Solovyova Gora, Sudbury and other deposits were proved and supplemented. The hypotheses became laws; exact, clear, exhaustive laws.

The results of direct observations of the solidified primordial magma proved conclusively and irrevocably that the neoneptunist-transformists were in the wrong, and that the magmatists were right.

Yes, the magmatists were right! Now, working on the basis of their theories, super-deep drilling could be organized in various parts of the globe, this time to discover more and more new deposits of economically useful minerals. Economists began to play their part in the computations. They calculated that all drilling costs would be more than redeemed by the

accumulations of platinum, diamonds, nickel, rare and dispersed elements and many, many others.

Especially striking were the results obtained by the scientists in the central part of the lava lake. This part was reached last, after all the others. But here too, the calculations of the magmatists were confirmed. A section of a volcanic pipe rose up before the eyes of the scientists, chock-full of diamonds!

Yes, diamonds originated under the Earth's crust in gigantic volcanic pipes. Together with the primordial matter they penetrated the whole of the Earth's crust, and wherever we see these volcanic pipes in natural conditions, near great faults in the Earth's crust, the same processes had occurred as in this gigantic experiment.

All these results were a triumph of scientific foresight!... But here the film ended and the lights went on.

Hardness Also Has Its Limit

Now the film producer had to show the opposite point of view. He had to show the views of those scientists who believe that a solid mass of solid matter underlies the Earth's crust. The screen lighted up again, and again the projector began to purr.

The metallic voice of the announcer is heard again: "Five metres left to go to reach the Earth's mantle. Three metres.... Two metres.... One!...."

Again thunderclaps. Matter bursts out from inside the Earth.

Again a super-high-speed photographic unit registers all that happens. Mangled columns of drill-pipes come flying out of the drill-hole, followed finally by the broken head of the drill unit.

But what is this? There is no magma, no outbursts of gas. A colossal obelisk is forced up, consisting of some substance, that no one has ever seen before.

When at last it became possible to approach the zone of the drill-hole, everybody was struck with wonder. An extraordinary substance had forced its way up from the Earth's mantle. Scientists attempted to break a piece off the obelisk, but their efforts were in vain. Even the super-hard mineral diamond could not even so much as scratch the subcrust substance. Super-hard borazon, the alloy of boron and nitrogen which cuts everything, even diamond, was also useless. Lasers, light-energy generators, were immediately brought into action. They develop a temperature of eight to nine thousand degrees. The ray of a laser cuts instantaneously through even the hardest diamond.

But lasers were also powerless. They left not a single scratch on this super-hard substance.

So that is why the velocity of seismic rays increases so sharply beyond the Moho boundary! They pass through this extraordinarily hard substance.

A group of blasters was despatched to the drill-hole. But even blasting was of no avail. Only special plasma guns developing a fantastic temperature of millions of degrees could break down the subterrestrial obelisk, throw it to the ground and cut it to pieces!

A material of incredible hardness had been extracted from under the ground. It was called mohite, after the Moho frontier. Mounted in a special unit, mohite cut through everything on the Earth's surface as a knife cuts through butter. Mohite caused a revolution in engineering. In changed the technology of metal working. Scientists calculated that it could be used for the most economic drilling of other super-deep holes sunk to obtain more of this super-hard material.

Metallurgists, chemists and geochemists began to determine the chemical composition of mohite. But could they approach this problem, seeing that mohite does not dissolve in acids? All methods of physicochemical analysis were also powerless.

Isotope analysis came to the rescue. By means of neutron analysis isotopes of a great variety of chemical elements were detected. Scientists were astonished when they examined the list. It turned out that mohite consisted of all the chemical elements of the Periodic Table. It was difficult to calculate the quantitative ratio of the elements. Assays are still being made in various laboratories all over the world. One thing is clear to the scientists; here is something quite new, unknown, and unstudied.

Especially great attention was devoted to mohite by the scientists of capitalist countries. Mainly because the appearance of mohite in engineering caused a great commotion on the stock markets in many countries of the world. The shares of all companies connected even indirectly with the diamond mining industry or

technologies making use of these diamonds, dived sharply. The drop in the shares of these companies caused those of other trusts, companies and concerns to drop too. The world was worried, indeed.

The use of mohite meant a change in the habitual way of life. Its appearance heralded a revolution in almost all branches of technology.

"There's No Magma Under the Crust!"

There is no magma! Scientists began to come to this conclusion long before the deep hole was sunk into the famous Moho discontinuity. This conclusion became self-evident after the extraordinary phenomenon which was established and registered by instruments let down together with the drilling equipment into the depths of the Earth's crust.

Not much attention was attached to it at first. The temperature registered by special instruments began to behave strangely. First, the curve stopped at a certain level, and then began to drop instead of rising. At 10 kilometres below the surface the temperature was already close to zero degrees Celcius! Still deeper the temperature passed into the subzero range....

This alarmed everybody. Where is the magma? What will be found when the hole reaches the Moho discontinuity? How to account for the mistake of the engineers who planned the unit? They designed the equipment to withstand a sharp rise in temperature as it sank further down. All their work was in vain.

New equipment had to be made in a hurry, new calculations performed, and new materials sought for super-deep drill-holes in a zone of high pressure and negative temperatures.

Meanwhile, incredible reports came in one after another.

The temperature kept on dropping with depth!...

"Report from the Temperature Front"—that is what the newspapers called this unusual information, which was accompanied by other data just as curious. That is when Academician Vernadsky's hypothesis, put forward as far back as 1934, was recalled. The hypothesis we discussed above. Unfortunately, the scientists, engineers and constructors who equipped the drill-hole had not taken it into account....

Circulating solutions were detected at a great depth. At about three kilometres immense reserves of drinkable water of the Narzan type were struck in the Caucasian well. At once new spas began to be planned and built. Deeper down the chemical composition of the subsoil waters changed. In the zone of transition from positive to negative temperatures water flows were encountered containing copper, nickel, cobalt and other elements.

And once more there arose the question: how are ore deposits formed? It seems that the magmatists were wrong in associating accumulations of various minerals with magmatic hearths. It appears that ore-containing solutions may penetrate even into the low temperature zones.

This conclusion astounded the scientists.

They would have to abandon their habitual conceptions about the formation of mineral deposits.

And finally a record depth was reached. The most interesting analysis was that of the core raised from a depth of 15 kilometres on the Kola Peninsula. Here the hole had passed through half the thickness of the Earth's crust. The rock raised from this depth turned out to be ordinary granite, very similar in appearance to those that crop out on the surface over a considerable part of the territory of the Kola Peninsula and Karelia.

But the greatest sensation was the age of these granites. Conventional methods were inadequate. Specially constructed atomic time counters registered an unheard-of age. Almost 100,000 million years! When designing this hole the scientists had expected to encounter some very ancient rocks. But not 100,000 million years! This refuted all the familiar ideas of the age of our planet.

Pieces of the core from the Kola Peninsula were tested in all the geochemical laboratories of the world, and the result was the same everywhere. Hence, the scientists who spoke of the immeasurable age of the Earth were right, after all.

By this time the results of drilling the other holes had come in. The Urals hole was just as interesting. Here a strange kind of substance was raised from a great depth. At first the scientists were baffled by the fact that over a comparatively large interval of several kilometres they had not been able to raise a single piece

of rock to the surface. At the same time, a sharp odour of gasolene spread all over the area round the drill-hole.

Then one of the drill foremen suggested that special devices should be designed capable of raising greatly compressed matter from the depths. A soil pump was made, and a dense black mass was raised to the surface. It was petroleum. Petroleum compressed to the solid state!

Hence, it was worth while prospecting for deep-seated oil in the Urals. Is petroleum, therefore, a product of the depths of the Earth?....

It turned out that we had been wrong in recommending that oil be sought only in the surface zones of the Earth's crust. The "Queen of the Depths" remains true to herself: she occurs at depths that for a long time were inaccessible to mankind. But now her chambers were opened. Now all oil prospecting work could be directed at greater depths!

And the planning institutions got down to work and started planning new wells as deep as the super-deep hole in the Urals.

But by this time more information began to come in. The hole in the Caspian district gave some interesting data. There they obtained not only solid petroleum, but a large number of petroleum products as well. One of them was ozokerite, or mineral wax, which owes its origin to the weathering of light petroleum. It has been known for a long time in certain parts of the Earth. It has been found in the district of Cheleken Island in the Caspian, and on the territory of Western Ukraine. Nobody ever

thought that there could be gigantic deposits of this wax-like substance at a great depth.

Still more striking news came from the super-deep drill-hole in the Kuril Islands district. There the rocks of the Moho frontier were struck for the first time. The hole sank into a substance which was under a very high pressure, as expected, but at a low temperature. When the substance was raised to the surface it was found to be an ordinary piece of compressed rock of the basalt type. It contained a large amount of different metals: copper, rare elements and other metals. The Kuril hole came across no melts.

The neoneptunists were triumphant! This confirmed their conclusions which for a long time had been considered doubtful. The world press was full of data which irrevocably defeated the magmatic theory of ore formation and mountain building.

Now everything was in order. Textbooks were quickly revised so that they no longer gave hypothetical ideas, but only actual facts. Projects appeared for drilling deep and super-deep shafts. Such shafts would start with an immense diameter of several scores of metres, so that they could gradually narrow to the conventional size.

The revolution in research techniques ushered in by the first five exploration holes opened out new horizons. There was always a long queue at the Academy of Sciences Building at the National Economic Achievements Exhibition. Here a diamond of the first water was on display, the size of a man. This was a synthetic diamond obtained on the basis of the data obtained from drilling the super-deep hole that

reached down into the low temperature zone. It appeared that diamonds of enormous size formed comparatively easily under those conditions!

So that the visitors would have no doubts that the diamond was of artificial origin, the words: "Peace, Work, Freedom" were laid out inside it in a combination of coloured minerals....

Finally, a core was raised from the zone of the Moho discontinuity. A piece of it was sent to the biological laboratory, where quite unexpectedly traces of life were discovered in it! This incredible find excited scientists even more than the hard rock and gigantic diamonds. Life does not confine itself to the thin film near the surface of the Earth. There is life at such inaccessible depths too!

Long before this hole had been drilled the Soviet scientist T. L. Ginsburg-Karagicheva detected bacteria at a depth of three kilometres in one of the wells of the Apsheron Peninsula. These bacteria differed from those on the surface in that they easily adapted their vital activities to life without access of oxygen. But the bacteria brought up from the super-deep holes assimilated oxygen. They were more highly organized than those discovered by Ginsburg-Karagicheva. They obtained oxygen by decomposing rocks into their constituent parts! They were a special kind of oxygen bacteria.

And again the question arose before the scientists: how did life originate on Earth? Again numerous hypotheses were put forward, consisting essentially in the statement that life had broken out on to the surface from the

depths of our planet. But how had it come into being there? That gave the scientists something to think about.

Beyond the Moho Discontinuity

Late at night when only the night shift of drilling engineers remained at the drill-hole on the Kuril Islands, a strange thing happened, which set the whole town of drillers into a flurry. Alarms were heard on all sides. The whole town, all its inhabitants gathered at the drill-hole.

And the drill-hole really was a sight! It was all aglow with a weird bright light. Tongues of cold flame shot out of people's fingertips, then jumped to their hair. The derrick was buzzing and humming strangely. A strong smell of ozone permeated the air.

This glow phenomenon has been known to man since antiquity. In ancient Rome it was known as the Fire of Castor and Pollux. In the 16th-17th centuries it was named after saints in whose honour various churches had been built. The glow was seen mainly on sharp objects in high places, and that is why people saw it most frequently on the cross at the top of a church. At one time it was called the Fire of Saint Erasmus; later it became known as Saint Elmo's Fire or simply the Elmo Fire. It was this "fire" that had so alarmed the drillers' settlement on the Kuril Islands.

The Elmo Fire arises, as a rule, when there is a high electric field in the atmosphere.

Sometimes it is very high—as much as 30 thousand volts per centimetre.

Measuring instruments were quickly put into action. It turned out that in this case the electric field was unusually high, running into millions of volts per centimetre!

Day after day the electric field recorded in the logbook rose higher and higher. The deeper the drilling equipment sank into the Earth, the higher it rose.

Experts from all countries were unable to find the reason for this phenomenon. Only gradually, as facts accumulated, did the answer begin to come to light. The investigators of the depths had come across a constant flow of electricity, the source of which is situated in the zone near the Earth's mantle.

The stray currents observed by scientists in the surface zone could not be compared with what was encountered near the Moho frontier. So the scientists who had put forward the idea of an Earth dynamo were right! This was a confirmation of their idea that the Earth is an immense electromagnet. But even those scientists had not thought that the electric field would be encountered so close to the Earth's surface, just below the crust. They said that the Earth dynamo is related to the electric current moving in the zone close to the Earth's core, underneath the mantle. And it suddenly turned out that there is an Earth dynamo near the Mohorovičić discontinuity as well!

Subsequent investigations of the electric field led to interesting conclusions. The value of the electric field varied depending on the

processes taking place on the Sun. Scientists established short-period variations near the Moho discontinuity, related to changes in the life of the Sun. They found daily, monthly and yearly variations. This confirmed the idea suggested by certain scientists that the life of the Sun and that of our Earth are related by common processes. Projects for utilizing the electric field in the Earth's bowels began to spring up in different countries. One of the significant ones was that of engineer Ivanov, who suggested building a Global Power Grid by drilling a series of super-deep wells. One of them should be sunk in the district of Prince of Wales Land, where the northern magnetic pole is situated, and another in Antarctica, at the southern magnetic pole. A number of intermediate wells would then have to be drilled in various parts of the globe, and they could be connected up into an integral power grid.

Mankind had received a free source of electricity of unheard-of power. This eliminated the necessity of building expensive power stations. The new power source opened out boundless prospects for the triumph of man over nature.

There was also a new project for utilizing heat drops. This term became especially common in engineering literature. The theory of heat drops had been developed by scientists long before. There had been a great deal of discussion at one time about a project for heating cities with cold water obtained by convection currents. Paradoxical as it may seem, cold water can be used to heat houses. The temperature drops

obtained in this super-deep well were very great. And the project for utilizing the thermal power of the depths was based precisely on the difference between the temperatures on the surface and in the depths.

Daring and audacious projects kept coming in one after another. There was a project for utilizing the radiation coming from the bowels of the planet. The radiation was discovered by means of special instruments lowered into the zone of the Moho frontier. It appeared that there is a tremendous flow of all-penetrating neutrinos and other particles from the centre of the Earth to its surface, that the Earth itself radiates these particles born of complex nuclear processes!....

But Who Is Right?

Uncertainty is worst of all. I could conjure up thrilling lengths of film in my imagination, but they made neither a screenplay, nor a film. You cannot make a picture just by sticking together three or four lengths of film, which are only related by the fact that they depict opposite scientific views!...

It often happens that the more you delve into a question, the more you realise how little you know. That is what happened to me with the screenplay. The only conclusion I came to from reviewing all the numerous opinions on the inner structure of the Earth was that we need more experiments. We must drill deep holes as soon as possible to open the substance

of the Earth's mantle. New instruments have to be designed and made which can tell us what there is under the cover of the mantle, in the zone of the core. Only after such hard facts and new sources of information have been obtained will we have new prospects before us.

The film producer and I finally came to the conclusion that no screenplay could be made as yet. We were obliged to admit that science still had no definite answers to the questions that were troubling us. Should we show the clash of opinions and discussions; the controversy? But would it not be better to do this in a feature film where there could be not only a clash of ideas, but a clash of characters as well? For the time being, yes. Afterwards science would have its say too.

While collecting material on the inner structure of the Earth I stopped looking for the geologists with whom I had discussed debatable questions a quarter of a century ago. I somehow got used to the idea that I had forever lost my friends of the XVII International Geological Congress.

But one day I received a thick letter with an invitation card to attend a Conference devoted to the centenary of the birth of V. I. Vernadsky. The dates: "1863-1963" were impressed in gold on a card bearing the Academician's portrait. A programme of the Conference was attached to the invitation card.

Newspapers and magazines published new facts about the life and activities of the great scientist. The most interesting to me was probably V. I. Vernadsky's letter to B. P. Lichkov,

written back in 1933 and published in the magazine *Priroda* (*Nature*). Vernadsky wrote:

"...We have imperceptibly arrived at a revolution in geology. It is very important to rid our conceptions of the cosmogonic hypotheses of the Earth; I believe that the Kant and Laplace hypotheses of molten Earth, etc., are fantasies and now an obstacle to our progress. I have thought so for a long time, from my youth, but now the idea has gained in stature. The picture that now presents itself is entirely different. The planet is a cold body; its regularly alternating shells are invariable in geological time and were created by geological processes. Why could not the present Earth form quickly (on the geological time scale) from a large 'meteorite' drawn by the attraction of the Sun?"

Now this revolution has matured, and to some extent is already taking place. That is why the jubilee of one of its forerunners was celebrated so extensively and solemnly.

The scientists who gathered to honour the memory of Vernadsky represented not only the Soviet Union. It was a kind of international congress. Reports were made and preliminary articles published by distinguished scientists from Hungary, the U.S.A., Canada, the Union of South Africa, France, Czechoslovakia, Rumania, the German Federal Republic, the German Democratic Republic, India, Japan and other countries.

Of course, reports were also submitted by Soviet scientists: academicians, corresponding members of the Academy of Sciences, doctors and candidates of science. The reports of both

Soviet and foreign scientists dealt with the physics and chemistry of the Earth's crust, mantle and core. Various trends in geology, geochemistry and geophysics were reflected in them.

All the participants of the Conference were accommodated in various Moscow hotels, but most of the delegates were given rooms in the central hotels.

Without making arrangements, many of the participants of the Conference gathered in the "Metropole" Restaurant on the eve of the opening. Just like twenty-five years before, renowned scientists sat down to eat, while youth seethed everywhere in the hall.

And suddenly I heard a young voice:

"Mineral formation is not due to magma!"

What was that? A quarter of a century has passed, and youth has switched over to the transformists' camp?

But I had been too hasty. Magmatists turned up immediately and the conversation soon became heated, with arguments coming from all sides.

And again someone suggested:

"Let's go and ask the chief scientists; let's find out what they think!..."

And the noisy crowd of young scientists moved towards the centre of the hall....

I did not bother to write down the names of those young men.

Who knows, maybe twenty-five years from now one of them will be finishing this book and will look up his friends himself.

TO THE READER

Peace Publishers would be grateful for your comments on the content, translation and design of this book. We would also be pleased to receive any other suggestions you may wish to make. Our address is: 2, Pervy Rizhsky Pereulok, Moscow, U.S.S.R.

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ABOUT THE BOOK

What is the inside of the Earth like; what mysteries does its mantle conceal? What will the sensitive feelers of superdeep holes encounter there - boiling liquid magma or superhard matter, unimaginably high temperatures or cold approaching absolute zero?

Science cannot as yet give the exact answers to these questions, though myriads of different hypotheses have been put forth.

This book tells haw scientists are ferreting out the secrets of the deeper zones of the Earth; its subject is the romance of the searches and tenacious investigations carried out by geologists who have devoted themselves to the study of the depths of our planet.

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